BOW LAKE
1988-89
LAKES LAY MONITORING PROGRAM

by

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edited by

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NEW HAMPSHIRE LAKES LAY MONITORING PROGRAM

NH LLMP

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To obtain more information about the NH Lakes Lay Monitoring Program (NH LLMP) contact the Coordinator (J.Schloss) at (603) 862-3848
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PREFACE

This report contains the findings of a water quality survey of Bow Lake, New Hampshire, conducted in the summers of 1988 and 1989 by the Freshwater Biology Group (**FBG**) of the University of New Hampshire and the Bow Lake Camp Owners Association.

The report is written with the concerned lake resident in mind and contains a brief, non-technical summary of 1988 and 1989 results as well as more detailed "Introduction" and "Results and Discussion" sections. The description of methods and materials used by the Lay Monitors and the Freshwater Biology Group has been included in an appendix. While it is common practice to exclude this type of section from a "general" writing such as this, it is our goal to provide program participants with a complete report which can stand on its own for comparison to past as well as future lake studies.

Graphic display of data is included, in addition to listings of data in appendices, to aid visual perspective. Other appendices contain various supporting materials including a glossary of terms commonly used in this and other reports on water quality. The more adventurous reader is referred to these last sections, as well as the materials cited in the references section, if there is interest in learning more about the dynamics of fresh water systems.

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ACKNOWLEDGEMENTS

1989 was the sixth year of participation in the Lakes Lay Monitoring Program (**LLMP**) for the Bow Lake monitors. The Lay Monitors were James McCarthy, Carl Gustofeson and Richard Sawyer. The coordinator for the Bow Lake Camp Owners Association was again Dr. Steven Steinmuller. The Freshwater Biology Group (**FBG**) congratulates the monitors on the quality of their work, and the time and effort put forth. We encourage other interested members of the Bow Lake Camp Owners Association to continue monitoring during the 1990 season. Funding for the program was provided by the Bow Lake Camp Owners Association.

The Freshwater Biology Group is a not-for-profit research program co-supervised by Dr. Alan Baker and Dr. James Haney and coordinated by Jeffrey Schloss. Members of the **FBG** summer field team included Jeffrey Schloss, Katherine Maroney, Beth Ferrari, Barent Rice, Maura Callahan, Elizabeth LaPointe and David Cederholm. Other **FBG** staff assisting in the fall were: Bonnie Bruce, Roger Caron, Robert Craycraft and John Ferraro.

The **FBG** acknowledges the University of New Hampshire Cooperative Extension for funding and furnishing office, laboratory and storage space. The Department of Plant Biology provided accounting support and the UNH Office of Computer Services provided computer time and data storage allocations.

Participating groups in the **LLMP** include: The New Hampshire Audubon Society, Derry Conservation Commission, Dublin Garden Club, Nashua Regional Planning Commission, Center Harbor Bay Conservation Commission, Governor's Island Club Inc., Little Island Pond Rod and Gun Club, Walker's Pond Conservation Society, United Associations of Alton, the Pemaquid Watershed Study Group, the associations of Baboosic Lake, Beaver Lake, Berry Bay, Big Island Pond, Bow Lake Camp Owners, Lake Chocorua, Crystal Lake, Dublin Lake, Goose Pond, Great East Lake, Lake Kanasatka Watershed, Langdon Cove, Long Island Landowners, Lovell Lake, Mascoma Lake, Mendum's Pond, Merrymeeting Lake, Moultonbouro Bay, Lake Winnipesaukee, Naticook

Lake, Newfound Lake, Nippo Lake, Perkins Pond, Pleasant Lake, Silver Lake (Hollis), Silver Lake (Harrisville), Silver Lake (Madison), Squam Lakes, Lake Sunapee, Sunset Lake, Lake Winona, and Wentworth Lake and the towns of Alton, Amherst, Hollis, Madison, Merrimack, Strafford, Tuftonboro and Wolfeboro.

BOW LAKE

1988-89 NON-TECHNICAL SUMMARY

Weekly monitoring of Bow Lake was undertaken by the volunteer monitors from July 28 to September 27 in 1988 and from June 20 to September 9 in 1989. An in-depth analysis of Bow Lake was conducted by the Freshwater Biology Group on September 19, 1989.

1) Water transparency at Bow Lake was high, the sign of a clear and unproductive lake. The secchi disk was visible as far down as 6.3 meters (20.5 feet) in 1988 and 7.5 meters (24.4 feet) in 1989. The transparency averages were 5.1 (1988) and 5.6 (1989) at site 1 Ledges and 5.1 (1988) and 5.5 (1989) meters at site 3 Bennett. This indicates the deepwater sites on the lake are relatively low in dissolved color and suspended matter such as algae and particulates. The 1989 transparency averages are higher than the 1988 averages (i.e. the lake was clearer in 1989) at both sampling stations.

2) Chlorophyll a concentrations for the surface waters of Bow Lake were at low levels in 1988 and increased to moderate levels in 1989. Chlorophyll levels indicate the extent of algae growth in the water. Concentrations in the mixed layer of water averaged 1.9 milligrams per cubic meter (mg m^{-3}, equivalent to about 1.9 parts chlorophyll per billion parts water) in 1988 and 3.4 mg m^{-3} in 1989 at site 1 Ledges. Chlorophyll concentrations at site 3 Bennett averaged 2.2 mg m^{-3} in 1988 and 3.5 mg m^{-3} in 1989. Generally, concentrations below 3 mg m^{-3} are common to less productive, clear, oligotrophic lakes and values above 7 mg m^{-3} are common in productive, eutrophic lakes. Thus Bow Lake would be classified as an unproductive, oligotrophic, lake in 1988 and a moderately productive (mesotrophic)

lake in 1989. Further testing shall discern whether this change is due to short term fluctuations or is a trend towards increasing algal productivity.

3) Dissolved lakewater color levels for Bow Lake in 1988 were at moderate levels, 36.8 ptu (platinate color units), while color levels were were very low (12.1) in 1989 and considerably less than the average level of 28 ptu (platinate color units) in other program lakes. Small increases in water color from the natural breakdown of plant materials in and around a lake are not considered to be detrimental to water quality. However, increased color can lower water transparency, and hence, change the public perception of water quality.

4) Total phosphorus (nutrient) levels measured by the volunteer monitors in 1988 were low to moderate at the sites sampled with the exception of high levels at Petermans Brook (21.2 and 32.6 ppb on August 31 and September 13, respectively) and an early August sample taken in the bottom waters, hypolimnion, of site 1 Ledges (19.8 ppb). 1988 phosphorus levels were in the range of 4.6 to 32.6 ppb. Phosphorus sampling was undertaken by the FBG at the deep sites 1 Ledges and 3 Bennett on September 19, 1989. The phosphorus levels remained low at the time of sampling with a range of 4.0 to 8.4 ppb which is well below the level of 15 ppb commonly thought of as the boundary between less productive and more productive lakes.

5) The pH of the surface waters of the lake, measured by the FBG and the volunteer monitors in 1989, remains within the optimum range for most aquatic organisms. The alkalinity of the lake remains low, about 3 units lower than the average for LLMP program lakes. The pH and alkalinity data indicate that Bow Lake seems to have a low, but sufficient, buffering capacity at this time to resist fluctuations in pH due to acid loadings.

6) The specific conductivity of the deep sites on Bow Lake was moderate in 1989. High conductivity values can indicate the presence of septic leachate or de-icing salt runoff.

7) In-depth analysis at the deep sites disclosed the typical temperature stratification patterns for northern temperate lakes. With the depth of the upper mixed layer extending to about 8.0 meters in 1989. Oxygen content of the bottom waters was low in 1989; bottom water oxygen concentration remained above 5 milligrams per liter (the minimum concentration required for successful reproduction and growth of most coldwater fish) only down to about 7.5 and 8.0 meters at sites 1 Ledges and 3 Bennett, respectively. Low oxygen and high carbon dioxide levels in the bottom waters suggests accumulation of organic matter from lake algal production and possibly watershed run-off.

8) For all measurements considered and averaged for the 1988 sampling season, Bow Lake would be classified as having low productivity, a relatively clear, oligotrophic lake. Increased algal levels and an **anoxic** hypolimnion in 1989 (see appendix C) indicate Bow lake is approaching more productive, mesotrophic, conditions. Continued monitoring in the comming year will help determine if these short term changes are an indication of a comming trend.

9) Comparisons between lay monitor and FBG data indicate that the volunteer monitors of Bow Lake are doing an excellent job of measuring water quality at both deep stations.

COMMENTS AND RECOMMENDATIONS

1) We recommend that each association, including the Bow Lake Camp Owners Association continue to develop their data base on lake water quality through continuation of the long term monitoring program. The data base will provide information on the short and long-term cyclic variability that occurs in the lake and eventually will enable more reliable predictions of water quality trends.

2) We recommend phosphorus testing to be done during early spring, during times of heavy use (ie: 4 July, Labor Day) and late in the season when septic systems have been put through a full seasons use. Deep site as well as tributary samples should be included.

3) We recommend lake water testing starting in June or earlier, if possible, to monitor the lakes reaction to the nutrients and acid loading that typically occur after ice- melt and during heavy spring rains.

4) Since the Bow Lake monitors have a high level of experience, we invite them to participate in our preliminary investigation of the effect of boat traffic on lakes. All that would be required is sampling in the morning and then the same day late in the afternoon on a "quiet day" followed by the same sampling approach on a day of heavy boat traffic. While only transparency measurements are necessary, a discount for sample processing will be offered to try to minimize costs of additional testing. Contact the LLMP coordinator for further information.

5) As a general addition to our Lakes Lay Monitoring Program, we recommend that each lake in the Program begin monitoring the condition of the fish taken from the lake. The "Fish Monitoring" will require at least one lay monitor to record the species, length and weight and collect a sample of fish scales for each fish examined. In most lakes this will involve periodic creel census of sport fishermen on the lake.

Length-to-weight ratios give a measure of the nutritional condition of the fish. Age analysis of the fish scales (to be done at UNH) will tell how old each fish is. Together, these variables can help to track changes in the condition of the fish populations in the lake, and, of course, the "health" of the lake.

INTRODUCTION

The New Hampshire Lakes Lay Monitoring Program

During the past decade the NH Lakes Lay Monitoring Program has grown from a university class project on Chocorua Lake to a comprehensive state-wide program with over 500 volunteer monitors and more than 75 lakes participating. Originally developed to establish a data-base for determining long-term trends of lake water quality for science and management, the program has expanded by taking advantage of the many resources that citizen monitors can provide. Current projects include: use of volunteer generated data for non-point pollution studies using a geographic based information system (GIS) in conjunction with the NH Office of State Planning, intensive watershed monitoring for the development of lake nutrient budgets, investigations of water quality and indicator organisms (fish condition, and stream invertebrates), and ground-truthing for remote sensing studies. Key ingredients responsible for the success of the program include innovative funding and cost reduction, assurance of credibility of data, practical sampling protocols and, most importantly, the interest and motivation of our volunteer monitors.

Importance of Long-term Monitoring

A major goal of a monitoring program is to identify any short or long-term changes in the water quality of the lake. Of major concern is the detection of cultural eutrophication: increases in the productivity of the lake, the amount of algae and plant growth, due to the addition of nutrients from human activities. Changes in the natural buffering capacity of the lakes in the program is also a topic of great concern, as New Hampshire receives large amounts of acid precipitation, yet most of our lakes contain little mineral content to neutralize this type of pollution.

For over a decade, data collected weekly from lakes participating in the **New Hampshire Lakes Lay Monitoring Program** have indicated there is quite a variation in water quality indicators through the open water season on the majority of lakes. Short-term differences may be due to variations in weather, lake use, or other chance events. Monthly sampling of a lake during a single summer provides some useful information, but there is a greater chance that important short-term events such as algal blooms or the lake response to storm run-off will be missed. These short-term fluctuations may be unrelated to the actual long-term trend of a lake or they may be indicative of the changing status or "health" of a lake.

To determine if a change in water quality is occurring, a lake must be sampled on a frequent basis over a substantial amount of time. A poorly designed sampling program may even mislead the investigator away from the actual trend: Consider the hypothetical lake in Figure 1. Sampling only once a year during August from 1982 to 1986 would produce a plot (Figure 2) suggesting a decrease in eutrophication. The actual long-term trend of the lake, increasing eutrophy, can only be clearly discerned by sampling additional times a year for a ten year period (Figure 1). Frequent monitoring carried out over the course of many summers can provide the information required to distinguish between short-term fluctuation ("noise") and long-term trends ("signal"). To that end, the lake must establish a long-term data base.

The number of seasons it takes to distinguish between the noise and the signal is not the same for each lake. Evaluation and interpretation of a long-term data base will indicate that the water quality of the lake has worsened, improved, or remained the same. In addition, different areas of a lake may show a different response. As more data is collected, prediction of current and future trends can be made. No matter what the outcome, this information is essential for the intelligent management of the lake.

There are also short-term uses for lay monitoring data. The examination of different stations in a lake can disclose the location of specific problems and corrective action can be initiated to handle the situation before it becomes more serious. On a lighter note, some associations post their weekly data for use in determining the best depths for finding fish!

It takes a considerable amount of effort as well as a deep concern for one's lake to be a lay monitor in the NH Lakes Lay Monitoring Program. Many times a monitor has to brave inclement weather or heavy boat traffic to collect samples. Sometimes it even may seem that one week's data is just the same as the next. Yet every sampling provides important information on the variability of the lake.

We are pleased with the interest and commitment of our lay monitors and are proud that their work is what makes the **NH LLMP** the most extensive, and we believe, the best volunteer program of its kind.

Purpose and Scope of This Study

1989 was the sixth year that monitoring of Bow Lake was undertaken by the Freshwater Biology Group and the Bow Lake Camp Owners Association. The program of sampling was designed to establish a long-term data base. Sampling emphasis was placed on two open water deep stations.

The primary purpose of this report is to discuss results of the 1988 and 1989 monitoring with emphasis on current conditions of Bow Lake including the extent of eutrophication and the lake's susceptibility to increasing acid precipitation. This information is part of a large data base of historical and more recent data compiled and entered onto computer files for New Hampshire lakes that include New Hampshire Fish and Game surveys of the 1930's and 1970's, the surveys by the New Hampshire Water Supply and Pollution Control Commission and the FBG surveys. Care must be taken when comparing current results with early studies. Many complications arise due to methodological differences of the various testing facilities and technological improvements in testing.

RESULTS AND DISCUSSION OF LAY MONITOR DATA

Monitoring of the deep sites of Bow Lake was undertaken in 1988 and 1989. Temperature, secchi disk depth, chlorophyll *a*, dissolved color and alkalinity were measured on a weekly basis from July through September in 1988 and on a biweekly basis from June through September in 1989. See Appendix A for the Lay Monitor data. Additional phosphorus samples were collected at designated shallow and tributary sites by the volunteer monitors in 1988.

Water Transparency

Secchi Disk depth is a measure of the water transparency. The deeper the depth of secchi disk disappearance, the more transparent the lake water; light penetrates deeper if there is little dissolved and/or particulate matter (which includes both living and non-living particles) to absorb and scatter it.

In the shallow areas of many lakes, the secchi disk will hit bottom before it is able to disappear from view (what is referred to as a "Bottom Out" condition). Thus, Secchi disk measurements are generally taken over the deepest sites of a lake. Transparency values of greater than 4 meters are typical of clear, less productive lakes. Values less than 2.5 meters are generally an indication of a very productive lake. In 1989 the average transparency for lakes participating in the NH LLMP was 6.2 meters with a range of 1.4 to 12.5 meters.

The average transparency of Bow Lake was 5.1 meters (range 4.5 to 6.3 meters) in 1988 and 5.5 meters (range 4.5 to 7.5 meters) in 1989.

Chlorophyll a

The chlorophyll a concentration is a measurement of the standing crop of phytoplankton and is often used to classify lakes into categories of productivity called trophic states. **Eutrophic** lakes are highly productive with large concentrations of algae and aquatic plants due to nutrient enrichment. Characteristics include accumulated organic matter in the lake basin and lower dissolved oxygen in the bottom waters. Summer chlorophyll a concentrations average above 7 mg m^{-3} (7 milligrams per cubic meter; 7 parts per billion). **Oligotrophic** lakes have low productivity and low nutrient levels and average summer chlorophyll a concentrations are generally less than 3 mg m^{-3}. These lakes generally have cleaner bottoms and high dissolved oxygen levels throughout. **Mesotrophic** lakes are intermediate in productivity with concentrations of chlorophyll a generally between 3 mg m^{-3} and 7 mg m^{-3}. In 1989 the average chlorophyll for lakes participating in the NH LLMP was 2.8 mg m^{-3} with a range of 0.1 to 54.4 mg m^{-3}.

Testing is sometimes done to check for **metalimnetic algal populations**, algae that layer out at the thermocline and generally go undetected if only epilimnetic (point or integrated) sampling is undertaken. Chlorophyll concentrations of a water sample collected in the thermocline is compared to the integrated epilimnetic sample. Greater chlorophyll levels of the point sample, in conjunction with microscopic examination of the samples (see Phytoplankton section below), confirm the presence of such a population of algae. These populations should be monitored as they may be an indication of increased nutrient loading into the lake.

Chlorophyll of the upper mixed water layer (epilimnion) of Bow Lake was sampled by the volunteer monitors in 1988 and 1989. Average chlorophyll concentrations were 1.9 mg m^{-3} (range 1.4 to 2.7 mg m^{-3}) at site 1 Ledges and 2.2 mg m^{-3} (range 0.8 to 5.0 mg m^{-3}) at site 3 Bennett in 1988. Average chlorophyll levels increased in 1989 to 3.4 mg m^{-3} (range 2.5 to 4.3 mg m^{-3}) at site 1 Ledges and 3.5 mg m^{-3} (range 2.6 to 5.0 mg m^{-3}) at site 3 Bennett.

Dissolved Color

The dissolved color of lakes is generally due to dissolved organic matter from **humic substances**, which are naturally-occurring polyphenolic compounds leached from decayed vegetation. Highly colored or "stained" lakes have a "tea" color. Such substances generally do not threaten water quality except as they diminish sunlight penetration into deep waters. Increases in dissolved water color can be an indication of increased development within the watershed as many land clearing activities (construction, deforestation, and the resulting increased run-off) add additional organic material to lakes. Natural fluctuations of dissolved color occur when storm events increase drainage from wetlands areas within the watershed. As suspended sediment is a difficult and expensive test to undertake, <u>both</u> dissolved color and chlorophyll information are important when interpreting the secchi disk transparency.

Dissolved color is measured on a comparative scale that uses standard chloroplatinate dyes and is designated as a color unit or ptu. Lakes with color below 10 ptu are very clear, 10 to 20 ptu are slightly colored, 20 to 40 ptu are lightly tea colored, 40 to 80 ptu are tea colored and greater than 80 ptu indicates highly colored waters. Generally the majority of New Hampshire lakes have color between 20 to 30 ptu.

Average dissolved color concentration at the two deep sites was 36.1 ptu during the 1988 sampling season and 12.1 ptu during the 1989 sampling season. The greatest color levels occurred in late September, 1988, at both deep stations.

Total Phosphorus

Of the two "nutrients" most important to the growth of aquatic plants, nitrogen and phosphorus, it is generally observed that phosphorus is the more limiting to plant growth, and therefore the more important to monitor and control. Phosphorus is generally present in lower concentrations, and its sources arise primarily through human related activity in a watershed. Nitrogen can be fixed from the atmosphere by many bloom-forming blue-green bacteria, and thus it is difficult to control. The total phosphorus includes all dissolved phosphorus as well as phosphorus contained in or adhered to suspended particulates such as sediment and plankton. As little as 15 parts per billion of phosphorus in a lake can cause an algal bloom.

Generally, in the more pristine lakes, phosphorus values are higher after spring melt when the lake receives the majority of runoff from its surrounding watershed. The nutrient is used by the algae and plants which in turn die and sink to the lake bottom causing phosphorus to decrease as the summer progresses. Lakes with nutrient loading from human activities and sources (Agriculture, Sediment Erosion, Septic Systems, etc) will show greater concentrations of nutrients as the summer progresses or after major storm events. Circulation of nutrients from the bottom waters of more productive lakes in late fall can result in algal blooms.

Bow Lake phosphours concentrations remained below the 15 ppb level when sampled in 1988 with the exception of high phosphorus levels at Petermans Brook (reaching as high as 32.6 ppb in mid September) and high levels in the bottom waters, hypolimnion, of the deep site, 1 Ledges (19.8 ppb). All phosphorus samples were in the range of 4.6 to 32.6 ppb.

Alkalinity

Alkalinity is a measure of the buffering capacity of the lake water. The higher the value the more acid that can be neutralized. Typically lakes in New Hampshire have low alkalinities due to the absence of carbonates and other natural buffering minerals in the bedrock and soils of lake watersheds.

Decreasing alkalinity over a period of a few years can have serious effects on the lake ecosystem. In a study on an experimental acidified lake in Canada by Schindler, gradual lowering of the pH from 6.8 to 5.0 in an 8-year period resulted in the disappearance of some aquatic species, an increase in nuisance species of algae and a decline in the condition and reproduction rate of fish. During the first year of Schindler's study the pH remained unchanged while the alkalinity declined to 20 percent of the pretreatment value. The decline in alkalinity was sufficient to trigger the disappearance of zooplankton species, which in turn caused a decline in the "condition" of fish species that fed on the zooplankton.

The analysis of alkalinity employed by the **Freshwater Biology Group** includes use of a dilute titrant allowing an order of magnitude greater sensitivity and precision than the standard method. Two endpoints are recorded during each analysis. The first endpoint (grey color of dye; pH endpoint of 5.1) approximates low level alkalinity values, while the second endpoint (pink dye color; pH endpoint of 4.6) approximates the alkalinity values recorded historically, such as NH Fish and Game data, with the methyl-orange endpoint method.

The average alkalinity of lakes throughout New Hampshire is low, approximately 9 mg per liter (calcium carbonate alkalinity), while the average alkalinity of the lakes studied by the **Freshwater Biology Group** in the NH LLMP is approximately 6.0 mg per liter. When alkalinity falls below 2 mg per liter the pH of waters can greatly fluctuate. Alkalinity levels are most critical in the spring when acid loadings from snowmelt and run-off are high, and many aquatic species are in their early, and most susceptible, stages of their life cycle.

Average alkalinity at Bow Lake was 2.7 mg per liter in 1988 and 3.5 mg per liter in 1989, which is low for a New Hampshire Lake and less than the average for **NH LLMP** program lakes. However, Bow Lake has sufficient alkalinity to buffer against acid input and avoid wide variations in the pH caused by acid rain.

RESULTS AND DISCUSSION OF FBG DATA

The Freshwater Biology Group (FBG) visited Bow Lake on 19 September 1989. The lake was sampled for several chemical, physical and biological parameters at two deep stations. Chlorophyll a, secchi disk transparency, alkalinity and dissolved color measured during the **FBG** field team visit fall within the ranges found by the lay monitors throughout the sampling season, indicating good corroboration between lay monitor and FBG data.

Water Transparency

The secchi disk depths measured by the FBG were 6.7 meters at both deep sites sampled: 1 Ledges and 3 Bennett.

Chlorophyll a

The chlorophyll a concentration in the surface waters was at moderate levels (4.7 mg m^{-3}) at both deep sites. Mid lake chlorophyll levels were slightly higher (5.3 mg m^{-3}) at both deep sites indicating layering of algae in the thermocline.

Dissolved Color

Dissolved color was at 7.5 ptu at both deep stations in mid September.

Total Phosphorus

The phosphorus concentration on 19 September 1989 was low in the surface waters of both deep water stations. The deeper waters displayed no great accumulation of phosphorus. All phosphorus concentrations were in the range of 4.0 to 8.4 ppb on September 19.

Thermal Stratification in the Deep Water Sites

Lakes in New Hampshire display distinct patterns of temperature stratification, that develop as the summer months progress, where a layer of warmer water (the **epilimnion**) overlies a deeper layer of cold water (**hypolimnion**). The layer that separates the two regions characterized by a sharp drop in temperature with depth is called the **thermocline** or **metalimnion**. Some shallow lakes may be continually mixed by wind action and will never stratify. Other lakes may only contain a developed epilimnion and metalimnion. Bow lake became statified into three distinct layers during the summer months with the upper mixed layer extending to about 8.0 meters.

Dissolved Oxygen and Free Carbon Dioxide *

Oxygen is an essential component for the survival of aquatic life. Submergent plants and algae take in free carbon dioxide and create oxygen through **photosynthesis** by day. **Respiration** by both animals and plants uses up oxygen continually and creates **carbon dioxide**. Dissolved oxygen profiles determine the extent of declining oxygen concentrations in the lower waters. High carbon dioxide values are indicative of low oxygen conditions and accumulating organic matter. For both gases, as the temperature of the water decreases, more gas can be dissolved in the water.

The typical pattern of clear, unproductive lakes is a slight decline in hypolimnetic oxygen as the summer progresses. Oxygen in the lower waters is important for maintaining a fit, reproducing, cold water fishery. Trout and salmon generally require oxygen concentrations above 5 mg per liter (parts per million) in the cool deep waters. On the other hand, carp and catfish can survive very low oxygen conditions. Oxygen above the lake bottom is important in limiting the release of nutrients from the sediments and minimizing the collection of undecomposed organic matter.

Bacteria, fungi and other **decomposers** in the bottom waters break down organic matter originating from the watershed or generated by the lake. This process uses up oxygen and produces carbon dioxide. In lakes where organic matter accumulation is high, oxygen depletion can occur. In highly stratified eutrophic lakes the entire hypolimnion can remain unoxygenated or **anaerobic** until fall mixing occurs.

The oxygen content of Bow Lake remained above 5 milligrams per liter only to about 7.5 and 8.0 meters at sites 1 Ledges and 3 Bennett, respectively. Moderate to high amounts of carbon dioxide in the bottom waters suggests the accumulation of organic matter generated from within the lake or running into the lake from the surrounding watershed.

Oxygen peaks occurring at surface and mid-lake depths during the day are quite common in many lakes. These characteristic **heterograde oxygen curves** are the result of the large amounts of oxygen, the by-product of photosynthesis, collecting in regions of high algal concentrations. If the peak occurs in the thermocline of the lake, metalimnetic algal populations (discussed above) may be present.

Specific Conductivity

The specific conductance of a water sample indicates concentrations of dissolved salts. Leaking septic systems and deicing salt runoff from highways can cause high conductivity values. Fertilizers and other pollutants can also increase the conductivity of the water. Conductivity is measured in micro**mhos** (the opposite of the measurement of resistance **ohms**) per centimeter, or more commonly, as micro-Siemans per centimeter. Conductivity of Bow Lake was moderate when sampled in September ranging from 74.5 to 77.4 micro-Siemans.

pH

The pH is a way of expressing the acidic level of lake water, and is generally measured with an electrical probe sensitive to hydrogen ion activity. The pH scale has a range of 1 (very acidic) to 14 (very "basic" or alkaline) and is logarithmic (ie: changes in 1 pH unit reflect a ten times difference in hydrogen ion concentration). Most aquatic organisms tolerate a limited range of pH and most fish species require a pH of 5.5 or higher for successful growth and reproduction.

Bow Lake pH was in the range of 6.2 to 6.7 at the two deep sites sampled. This indicates that the pH remains within the optimum range for most aquatic organisms. The range of surface water pH for all **LLMP** lakes was 5.2 to 7.2.

Alkalinity

Surface alkalinities at both deep sites were low; 3.3 mg CaCO3 per liter alkalinity. These results are comparable to the lay monitor readings.

Underwater Light

Underwater light available to photosynthetic organisms is measured with an **underwater photometer** which is much like the light meter of a camera (only waterproofed!). The **photic zone** of a lake is the volume of water capable of supporting photosynthesis. It is generally considered to be delineated by the water's surface and the level where light is reduced, by the absorption and scattering properties of the lake water, to one percent of the surface intensity. The one percent depth is sometimes termed the **compensation depth**. Knowledge of light penetration is important when considering lake productivity and in studies of submerged vegetation. Discontinuity (abrupt changes in the slope) of the profiles could be due to metalimnetic layering of algae or other particulates (discussed above). The underwater photometer allows the investigator to measure light at depths below the Secchi disk depth to supplement the transparency information. The compensation depth for Bow Lake at the time of FBG sampling was 9.9 meters at site 1 Ledges and 8.1 meters at site 3 Bennett. That is to say plants can grow down to 9.9 meters in Bow Lake.

Indicator Bacteria

Coliform bacteria in water indicate the possibility of fecal contamination. Although they are usually considered harmless to humans, they are much easier to test for than harmful pathogenic enteric bacteria (**Salmonella**, **Shigella** etc.) and viruses that may be present in fecal material. **Total coliform** includes all coliform bacteria which arise from the gut of animals or from vegetative materials. **Fecal coliform** are those specific organisms that inhabit the gut of warm blooded animals. Another indicator organism **Fecal streptococcus** (sometimes referred to as **enterococcus**) can also be monitored. The ratio of fecal coliform to fecal strep may be useful in suggesting the type of animal source responsible for the contamination. Desirable levels for a Class A water body is less than 50 total coliform organisms per 100 milliliters. If the coliform level rises above 150 organisms per 100ml swimming should be prohibited. Fecal Coliform testing was not done at Bow Lake.

Ducks and geese are often a common cause of high concentrations of coliform at specific lake sites. While waterfowl are important components to the natural and aesthetic qualities of lakes that we all enjoy, it is poor management practice to encourage these birds by feeding them. The lake and surrounding area provides enough healthy and natural food for the birds and feeding them stale bread or crackers does nothing more than import additional nutrients into the lake and allows for increased plant growth. As birds also are a host to the parasite that causes "swimmers itch" waterfowl roosting areas offer a greater chance for infestation to occur. Thus while leaving offerings for our feathered friends is enticing, the results can prove to be detrimental to the lake system and to human health.

Phytoplankton

The planktonic community includes microbial organisms that represent diverse life forms, containing photosynthetic as well as non-photosynthetic types, and including bacteria, algae, crustaceans and insect larvae (the zooplankton are discussed below in a separate section). Because planktonic algae or "phytoplankton" tend to undergo rapid seasonal cycles on a time scale of days and weeks, the levels of populations found should be considered to be most representative of the time of collection and not necessarily of other times during the ice-free season, especially the early spring and late fall periods.

The composition and concentration of phytoplankton can be indicative of the trophic status of a lake. Seasonal patterns do occur and must be considered. For example **diatoms**, tend to be most abundant in April-June and October-November, in the surface or epilimnetic layers of New Hampshire lakes. As the summer progresses, the dominant types might shift to **green algae** or **golden algae**. By late season **Blue-green bacteria** generally dominate. In nutrient rich lakes, nuisance green algae and/or bluegreen bacteria might dominate continually. After fall mixing diatoms might again be found to bloom.

Concentration of phytoplankton at the Bow Lake deep water sites was low to moderate with a range of 389 to 842 cells per milliliter. The dominant organisms at both deep sites were the green algae, Cosmarium. The types and diversity of algae present in the samples were typical of moderately productive New Hampshire Lakes.

Zooplankton

There are three groups of zooplankton that are generally prevalent in lakes: the **protozoa, rotifers** and **crustaceans**. Most research has been devoted to the last two groups although protozoa may be found in substantial amounts. Of the rotifers and the crustaceans, time and budgetary constraints usually make it necessary to sample only the larger zooplankton (macrozooplankton; larger than 80 or 150 microns; 1 million microns make up a meter). Thus, zooplankton analysis is generally restricted only to the larger crustaceans. Crustacean zooplankton are very sensitive to pollutants and are commonly used to indicate the presence of toxic substances in water. The crustaceans can be divided into two groups, the **cladocerans** (which include the "water fleas") and the **copepods**.

Macrozooplankton are an important component in the lake system. The filter feeding of the herbivorous ("grazing") species may control the population size of selected species of phytoplankton. The larger zooplankton can be an important food source for juvenile and adult planktivorous fish. All zooplankton play a part in the recycling of nutrients within the lake.

As discussed above for phytoplankton, zooplankton undergo seasonal population cycles and the results discussed below are most representative of the collection dates and not necessarily of other times during the ice-free season, especially during the early spring and late fall.

Late Summer sampling disclosed low concentrations of macrozooplankton at Bow Lake, Site 1 Ledges. However, diversity was high with three different species of the "water flea" Daphnia presant. These large cladoceran zooplankton can selectivly graze certain species of phytoplankton and also serve as an improtant food source for fish. The herbivorous (plant eating) calanoid copepod, Diaptomous, was the dominant zooplankton with the predatory cyclopoids as the sub-dominants. Site 3 Bennett had slightly higher zooplankton concentrations, especially for Diaptomous, while only one species of Daphnia was presant here. These differences might have been due to the different depths of the two sites.

Fish Condition

As with the plankton discussed above, the health of the fish species of a lake will be indicative of the overall water quality. Condition is determined by comparing the length of the fish to its weight. As would be expected, the heavier the fish for its length, the better its condition will be. By also examining a scale collected from the fish under a microscope, the approximate age and growth history can also be determined.

To assess the lake's health through the use of a **bio-indicator** such as fish, a substantial number of fish samples are required. Thus, it is important for **NH LLMP** participants interested in monitoring fish populations to provide at least 50 fish readings per species of fish. Many lakes have designated a separate coordinator for the fish condition program and have received participatory support from fishing clubs and bait and tackle shops.

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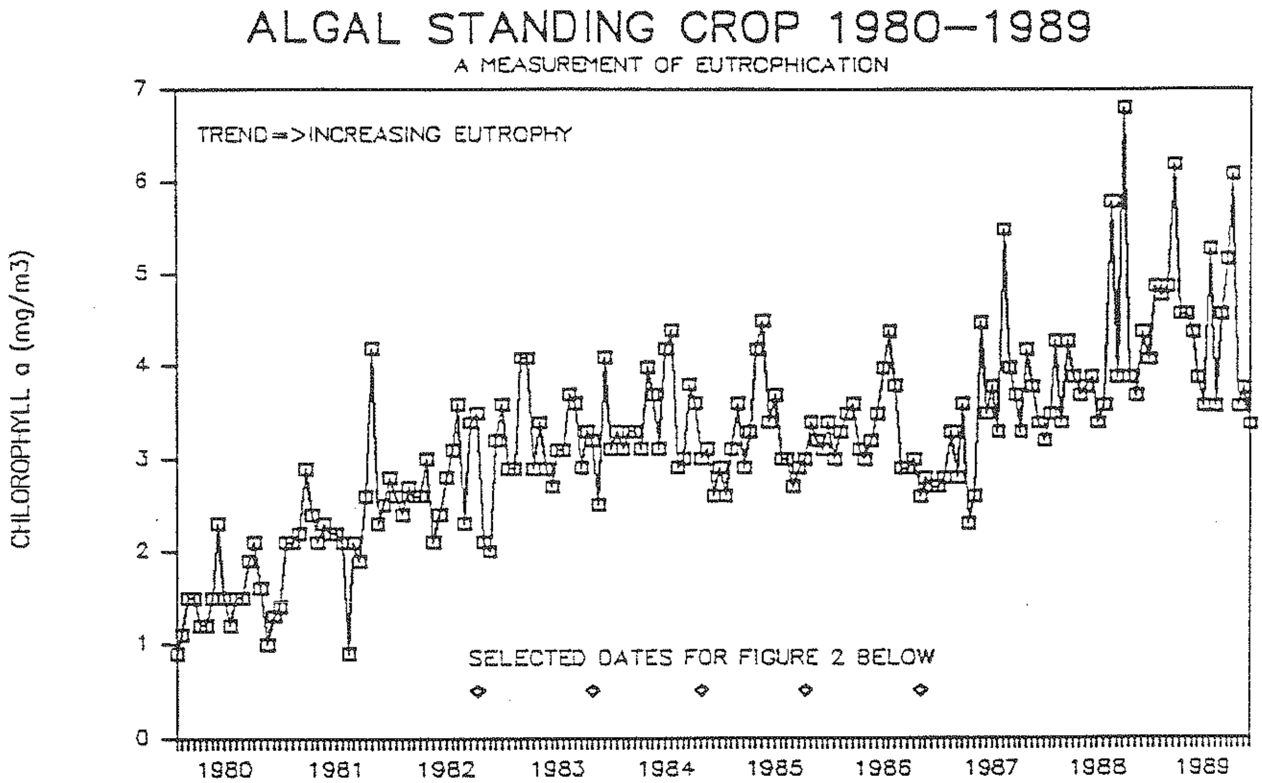
REPORT FIGURES



.Figure 1. The upper graph depicts weekly chlorophyll concentrations of a model lake measured weekly during ice-free conditions. The long-term trend is that of increased eutrophication (lake has become "greener"). Diamonds below the curve represent late summer (August) dates the data set was subsampled to create Figure 2.

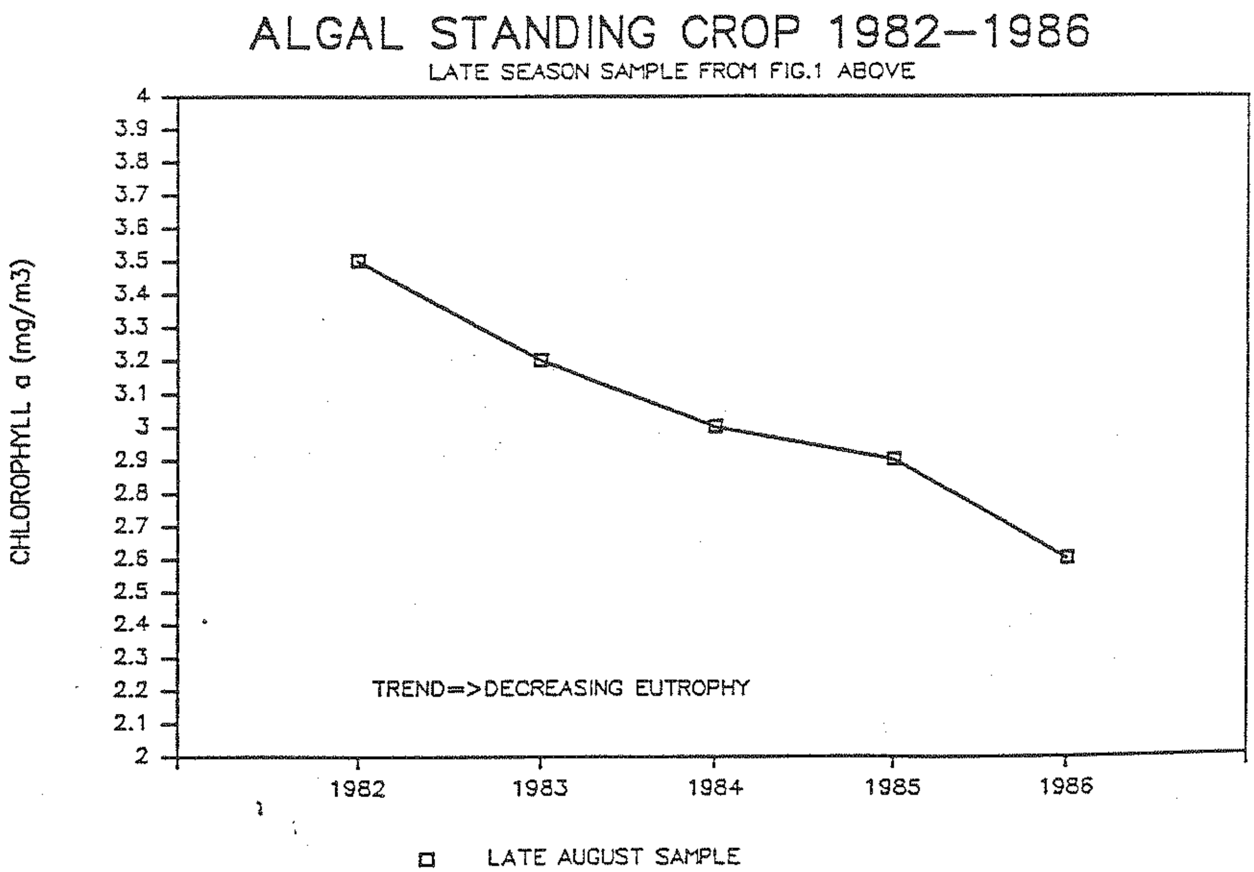


Figure 2. The lower graph depicts late summer chlorophyll data of the model lake in Figure 1. Note how limited sampling over a five year period suggests a much different trend, that of decreasing eutrophy. Thus, limited sampling can mislead the investigator of long-term trends.

Figure 3. Location of deep water sampling stations, 1 Ledges and 3 Bennett, on Bow Lake, Strafford, New Hampshire.

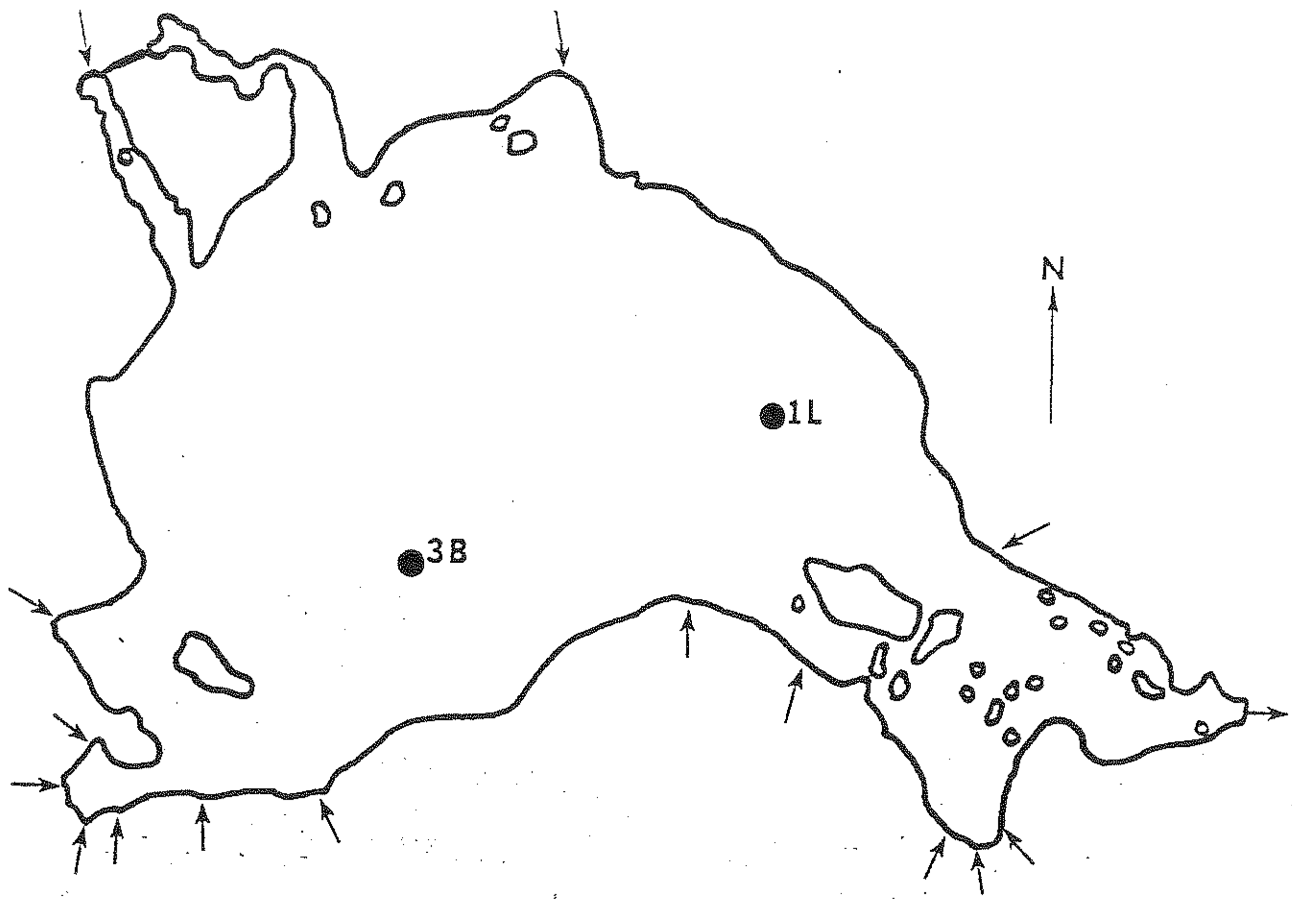
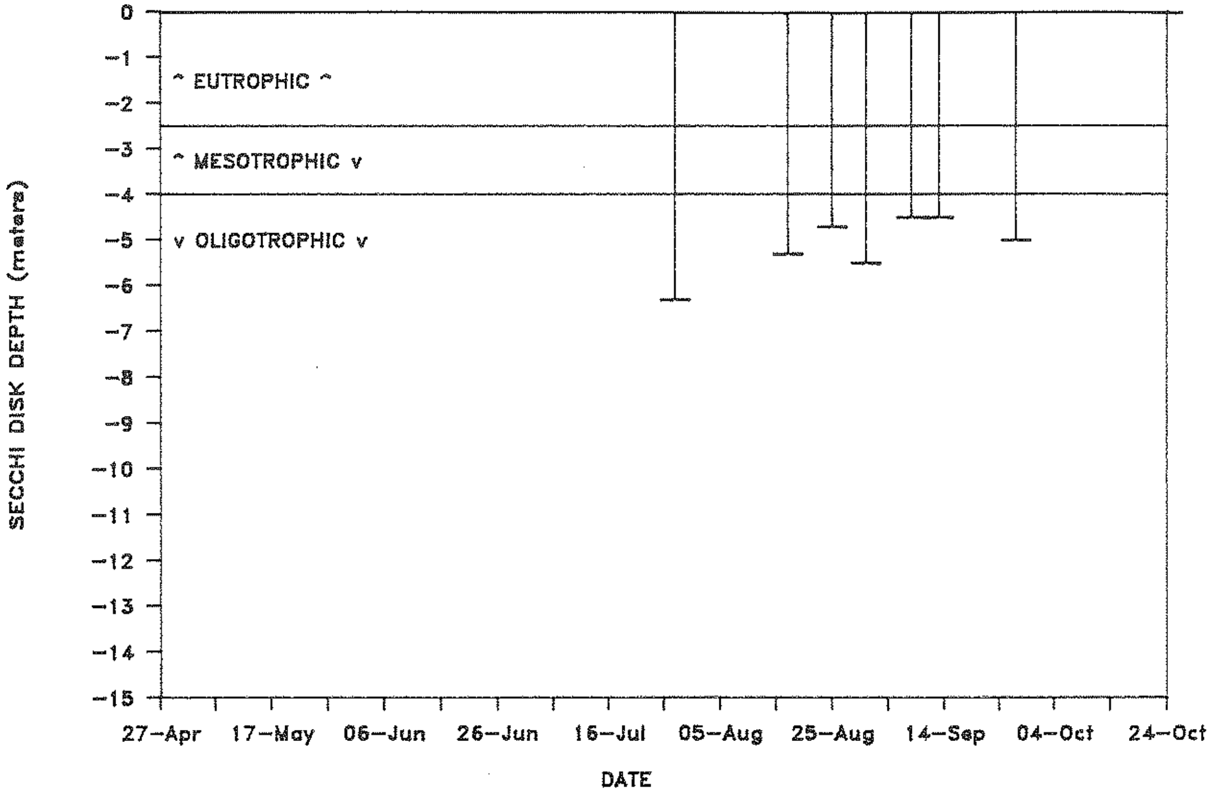

N
1L
3B

Figure 4. - Seasonal trends for secchi disk depth (water transparency) 1988 (A) Site 1 Ledges and (B) Site 3 Bennett. Solid lines on the plots border the ranges common to oligotrophic, mesotrophic and eutrophic lakes.

BOW LAKE – 1 LEDGES

SECCHI DISK TRANSPARENCY 1988



BOW LAKE – 3 BENNETT

SECCHI DISK TRANSPARENCY 1988

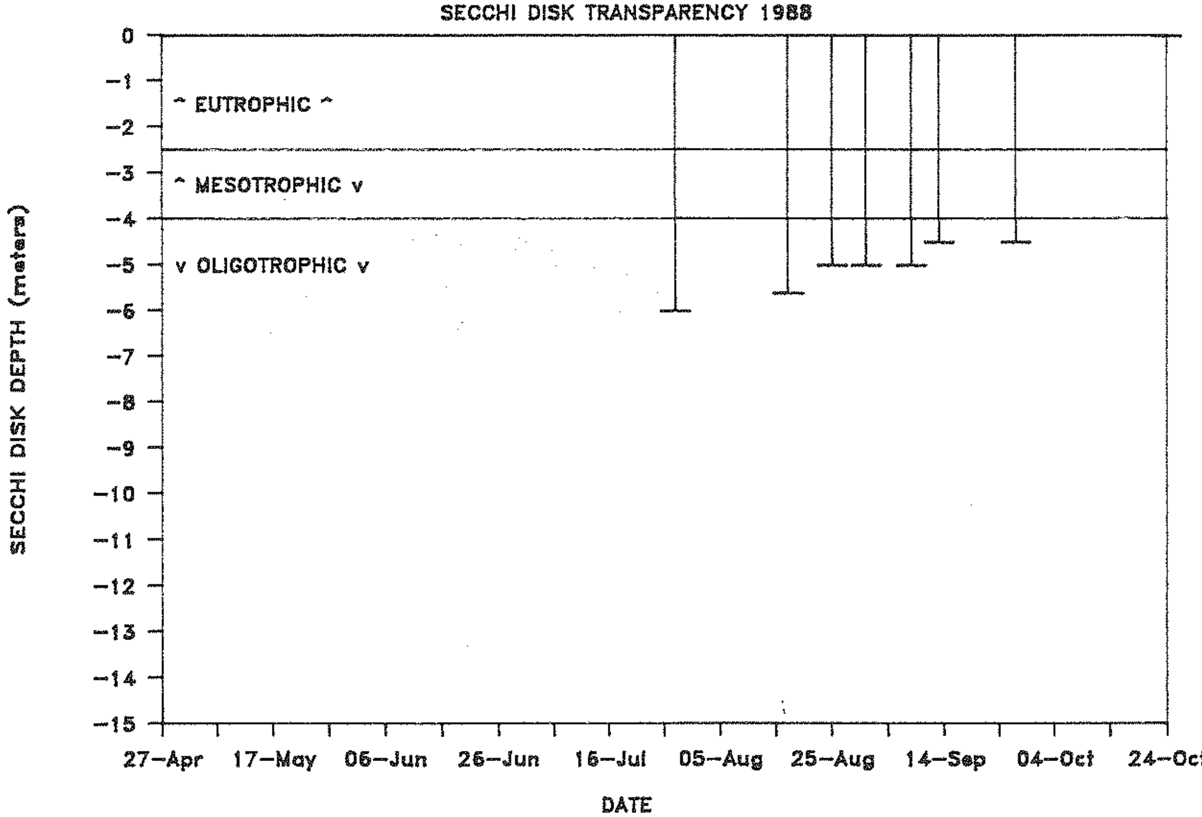
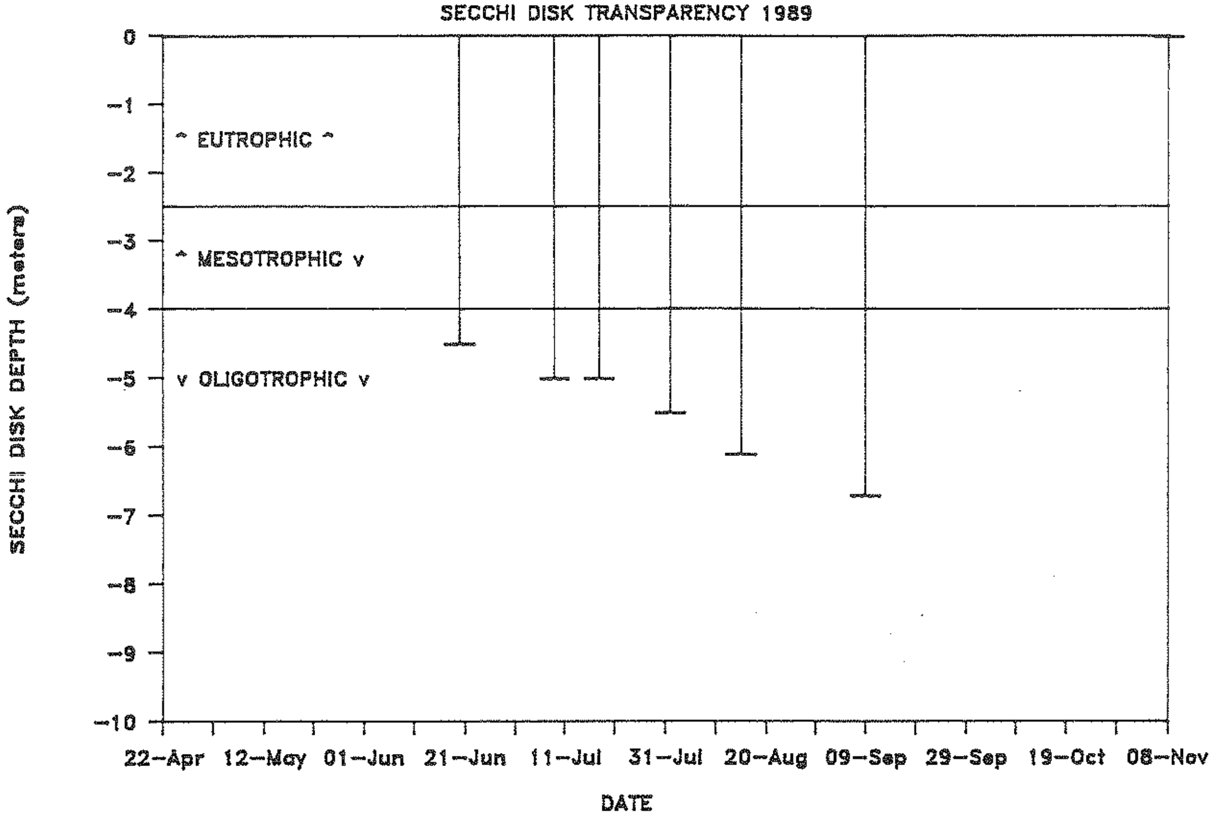


Figure 5. - Seasonal trends for secchi disk depth (water transparency) 1989 (A) Site 3 Bennett and (B) Site 1 Ledges. Solid lines on the plots border the ranges common to oligotrophic, mesotrophic and eutrophic lakes.

BOW LAKE 3 BENNETT

SECCHI DISK TRANSPARENCY 1989



BOW LAKE 1 LEDGES

SECCHI DISK TRANSPARENCY 1989

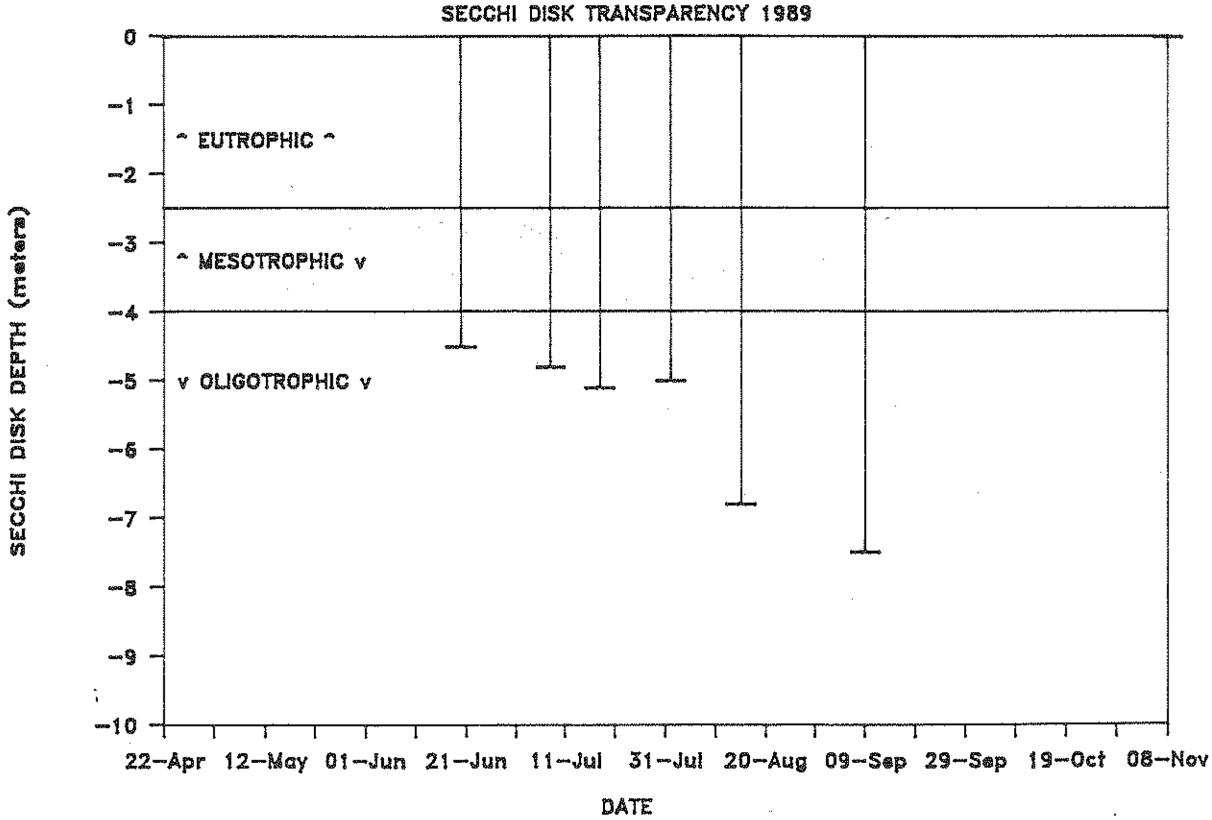
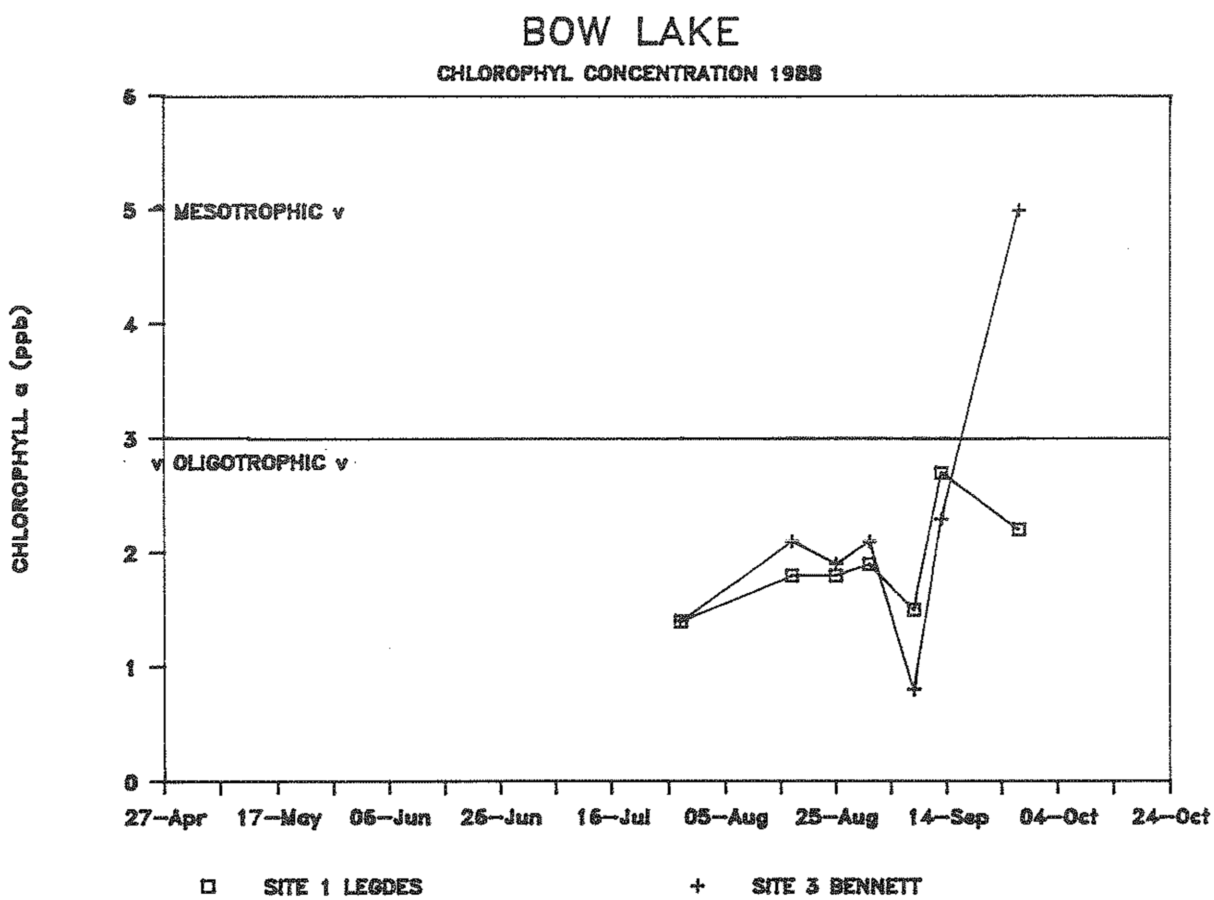


__**Figure 6**__. - Bow Lake 1988. Seasonal trends for Chlorophyll *a* concentration of lay monitor sites 1 Ledges (squares) and 3 Bennett (crosses). Chlorophyll *a* concentrations in mg per m^{-3} of chlorophyll *a*. The solid line on the plot borders the ranges common to oligotrophic and mesotrophic lakes.

__**Figure 7**__. - Bow Lake 1988. Seasonal trends for dissolved color of lay monitor sites 1 Ledges (squares), and 3 Bennett (crosses). Color expressed as platinum-cobalt units (ptu).


BOW LAKE
CHLOROPHYL CONCENTRATION 1988
CHLOROPHYLL a (ppb)
MESOTROPHIC v
v OLIGOTROPHIC v
0
1
2
3
4
5
6
27-Apr
17-May
06-Jun
26-Jun
16-Jul
05-Aug
25-Aug
14-Sep
04-Oct
24-Oct
SITE 1 LEGDES
SITE 3 BENNETT

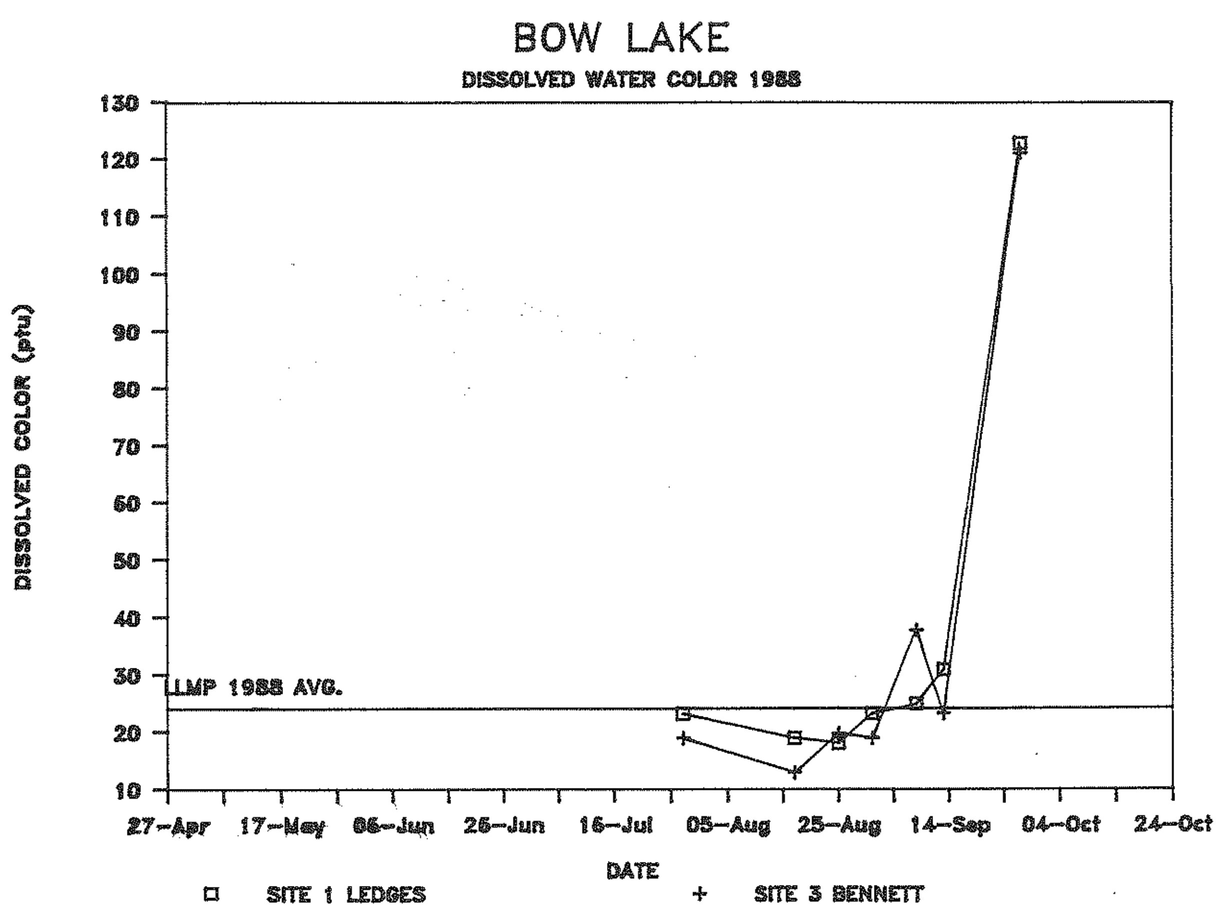
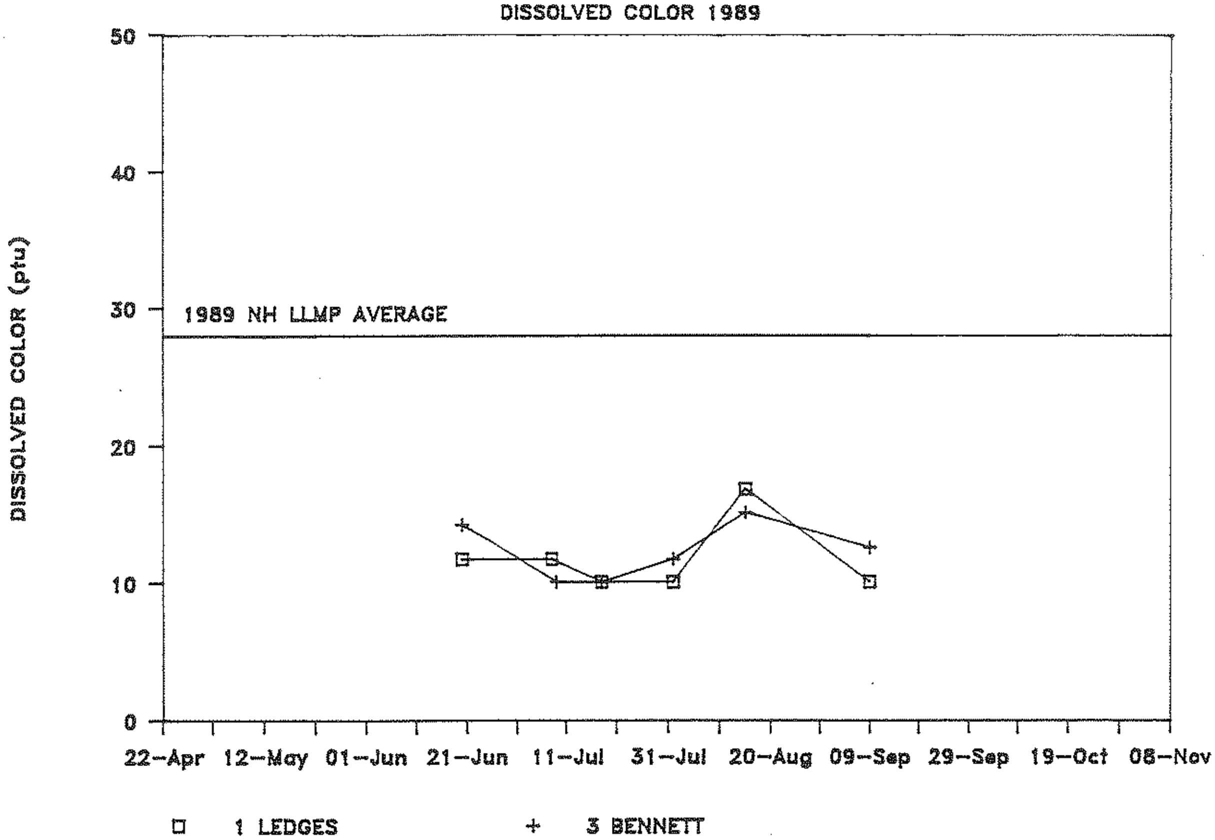

BOW LAKE
DISSOLVED WATER COLOR 1988
DISSOLVED COLOR (ptu)
LLMP 1988 AVG.
10
20
30
40
50
60
70
80
90
100
110
120
130
27-Apr
17-May
06-Jun
26-Jun
16-Jul
05-Aug
25-Aug
14-Sep
04-Oct
24-Oct
DATE
SITE 1 LEDGES
SITE 3 BENNETT

Figure 8. - Bow Lake 1989. Seasonal trends for dissolved color of lay monitor sites 1 Ledges (squares) and 3 Bennett (crosses). Color expressed as platinum-cobalt units (ptu).

Figure 9. - Bow Lake 1989. Seasonal trends for Chlorophyll *a* concentration of lay monitor sites 1 Ledges (squares) and 3 Bennett (crosses). Chlorophyll *a* concentrations in mg per m^{-3} of chlorophyll *a*. Solid lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes.

BOW LAKE

DISSOLVED COLOR 1989



BOW LAKE

CHLOROPHYLL CONCENTRATION 1989

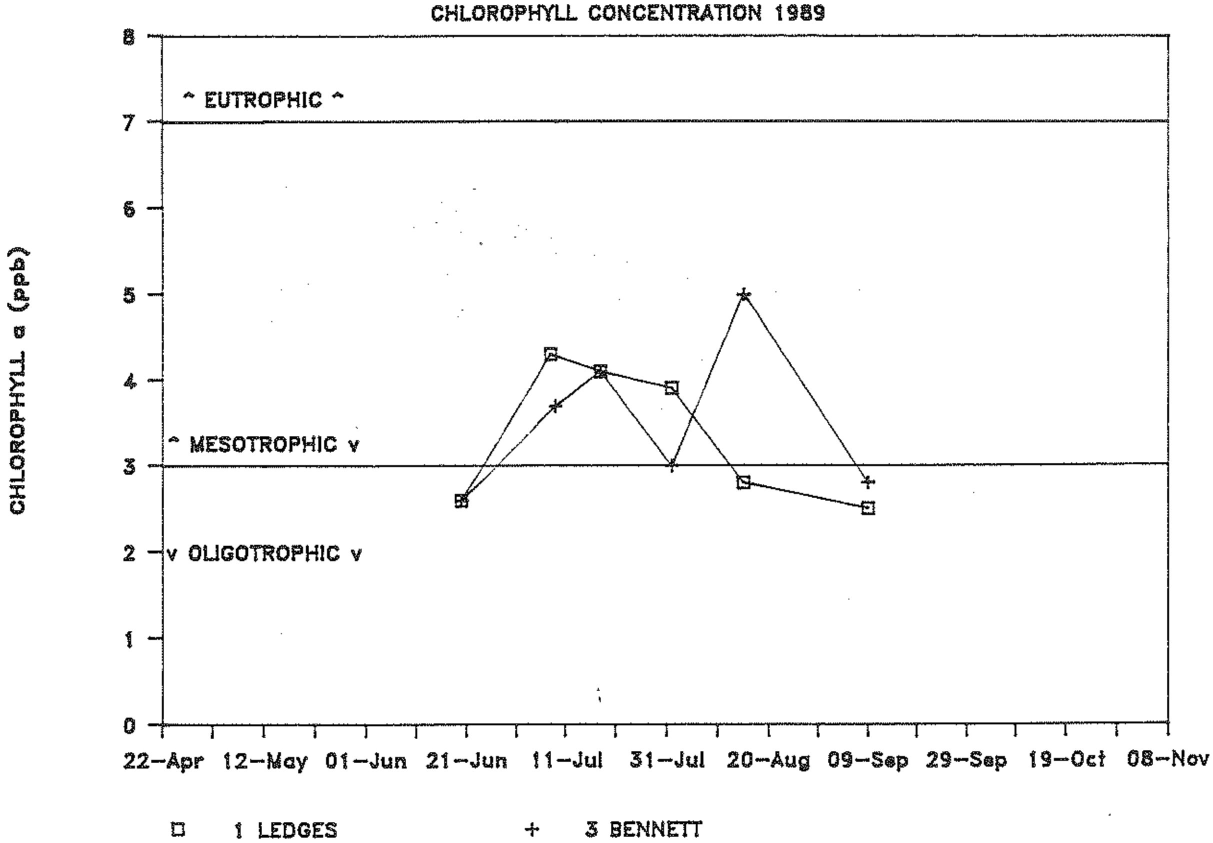
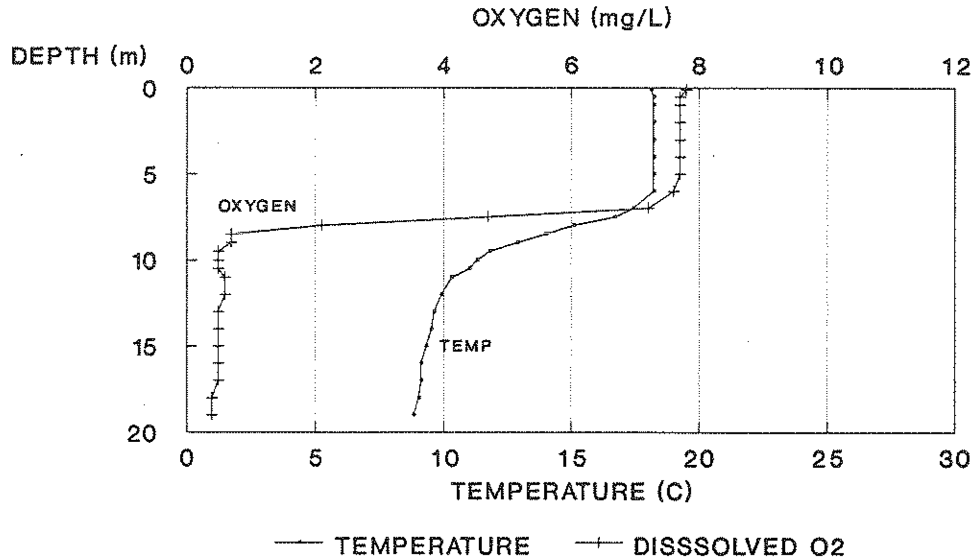


Figure 10. - Profiles of temperature (temp.) and dissolved oxygen (O_2) on 19 September 1989 at Bow Lake (A) Site 1 Ledges and (B) Site 3 Bennett. Units of measurement are as indicated. Oxygen and temperature were measured at one-half meter intervals. Notice the low oxygen levels in the deeper waters (see text).

TEMPERATURE - OXYGEN PROFILE
BOW LAKE SITE 1 LEDGES
SEPTEMBER 19, 1989



TEMPERATURE - OXYGEN PROFILE
BOW LAKE SITE 3 BENNETT
SEPTEMBER 19, 1989

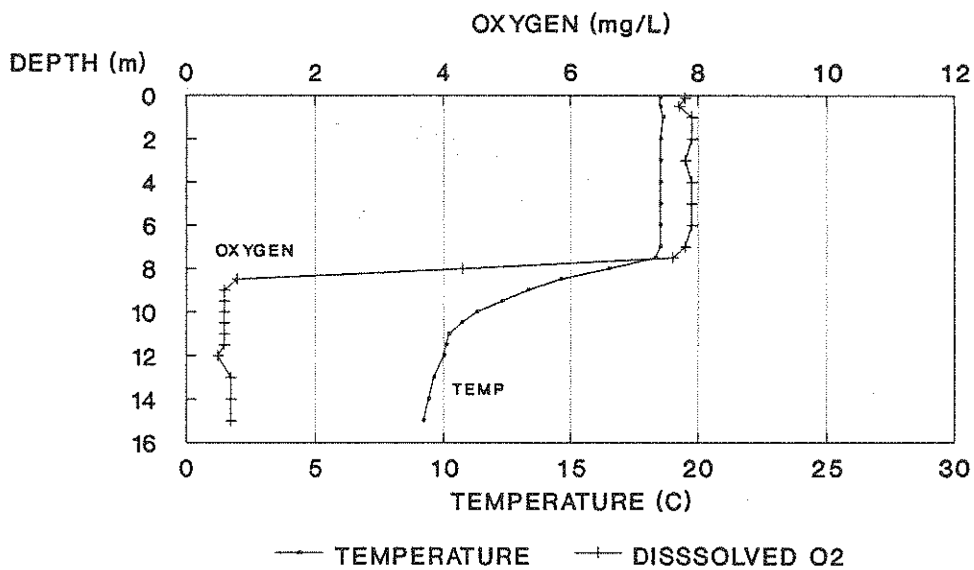
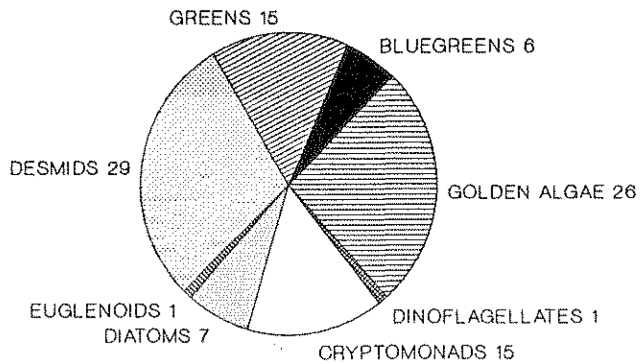


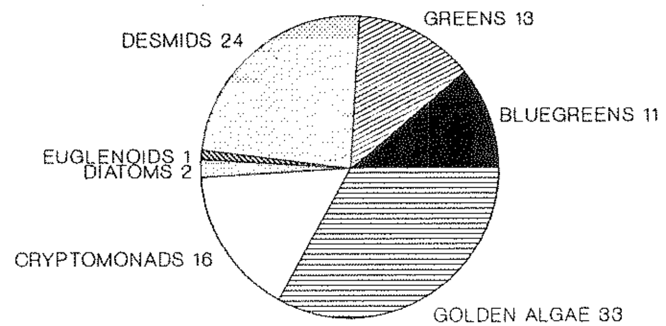
Figure 11. - Pie diagram of Phytoplankton Diversity at Bow Lake by Algal Class for deep sites 1 Ledges and 3 Bennett, September 19, 1989.

BOW LAKE

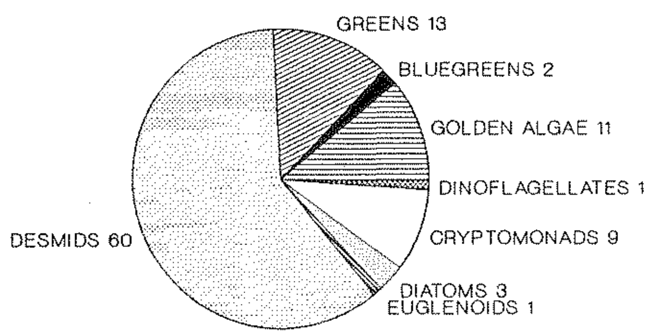
SITE 1 LEDGES
0-7.0 METERS
9 SEPTEMBER 1989



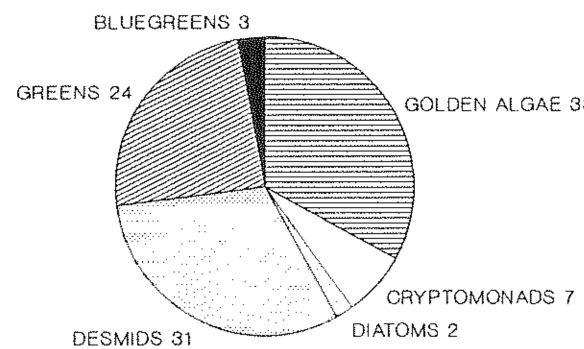
SITE 1 LEDGES
7.0 METERS
9 SEPTEMBER 1989



SITE 3 BENNETT
0-8.0 METERS
9 SEPTEMBER 1989



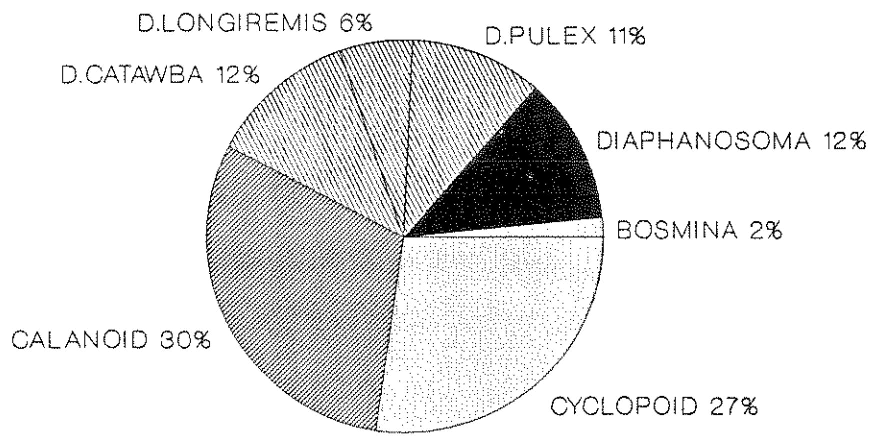
SITE 3 BENNETT
8.0 METERS
9 SEPTEMBER 1989



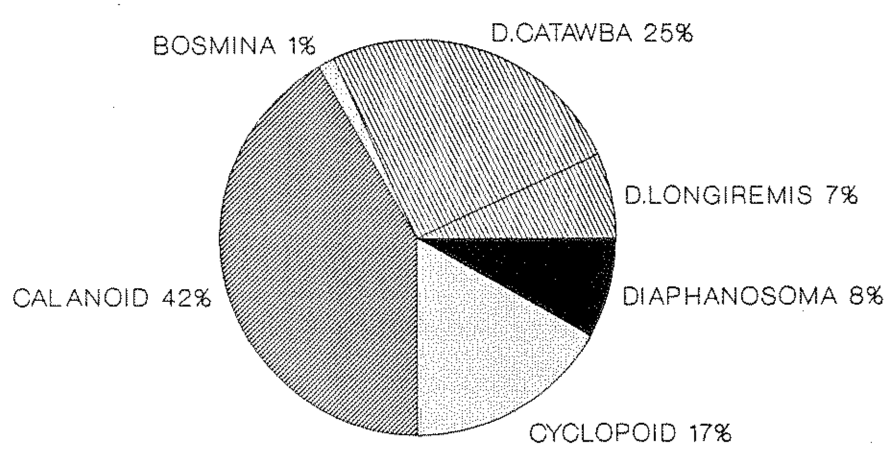
PHYTOPLANKTON ABUNDANCE % BY ALGAL GROUP

<u>Figure 12.</u> - Pie diagram of Macro-Zooplankton Diversity by group for Bow Lake site 1 Ledges and site 3 Bennett, September 19, 1989.

BOW 1 LEDGES 9/19/89
0-18 METERS



BOW 3 BENNETT 9/19/89
0-14.5 METERS

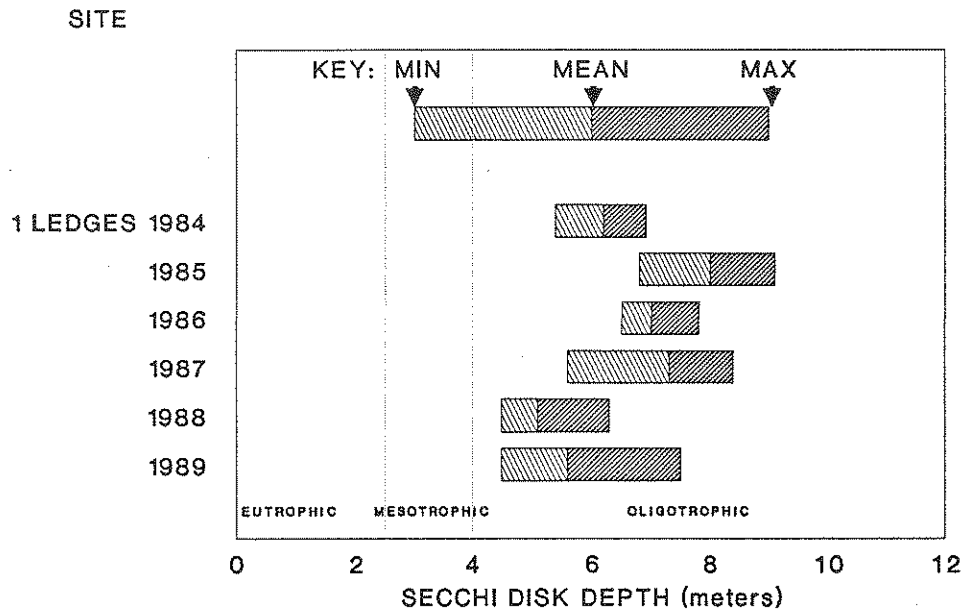


ZOOPLANKTON DENSITY % BY MACROZOOPLANKTON ORGANISM

Figure 13. - Comparison of Site 1 Ledges (1989) Secchi Disk Transparencies to previous yearly data. The patterns of the bars display the minimum, mean and maximum values for each year sampled while the length of the bar represents the total range of values. The higher the secchi disk value, the clearer the pond.

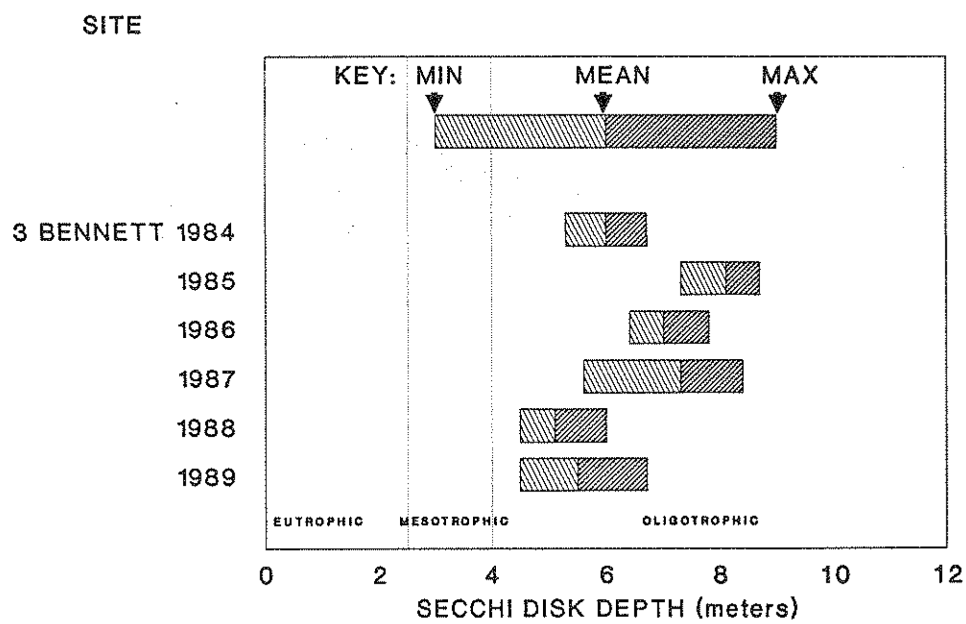
Figure 14. - Comparison of Site 3 Bennett (1989) Secchi Disk Transparencies to previous yearly data. The patterns of the bars display the minimum, mean and maximum values for each year sampled while the length of the bar represents the total range of values. The higher the secchi disk value, the clearer the pond.

COMPARISON: 1984 TO 1989 DATA
BOW LAKE SECCHI DISK DEPTH
SITE 1 LEDGES



The higher number = clearer water

COMPARISON: 1984 TO 1989 DATA
BOW LAKE SECCHI DISK DEPTH
SITE 3 BENNETT

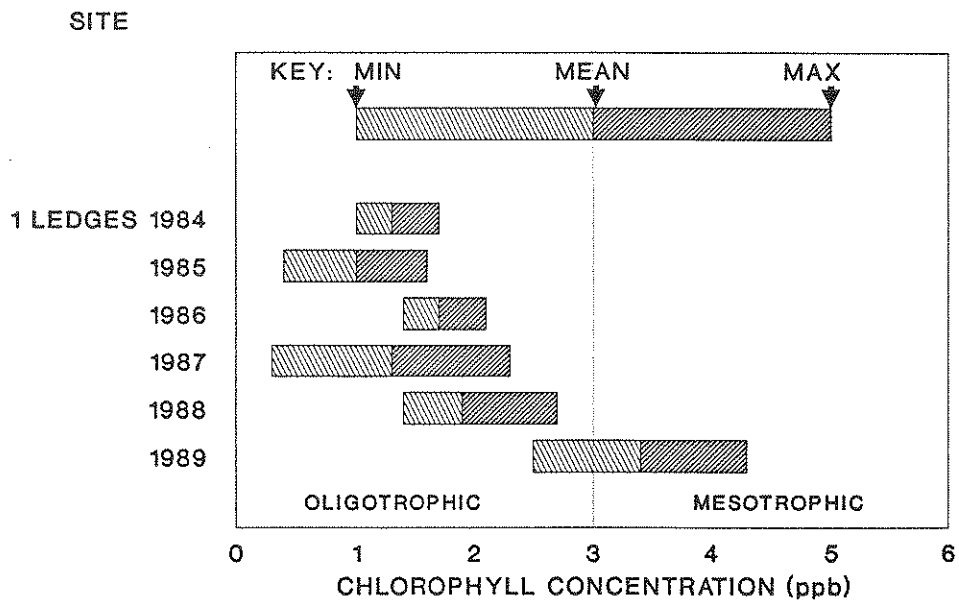


The higher number = clearer water

Figure 15. - Comparison of Site 1 Ledges (1989) Chlorophyll *a* Concentration with previous yearly data. The patterns of the bars display the minimum, mean and maximum values for each year sampled while the length of the bar represents the total range of values. The greater the concentration of chlorophyll *a* the "greener" the pond (more algae growth).

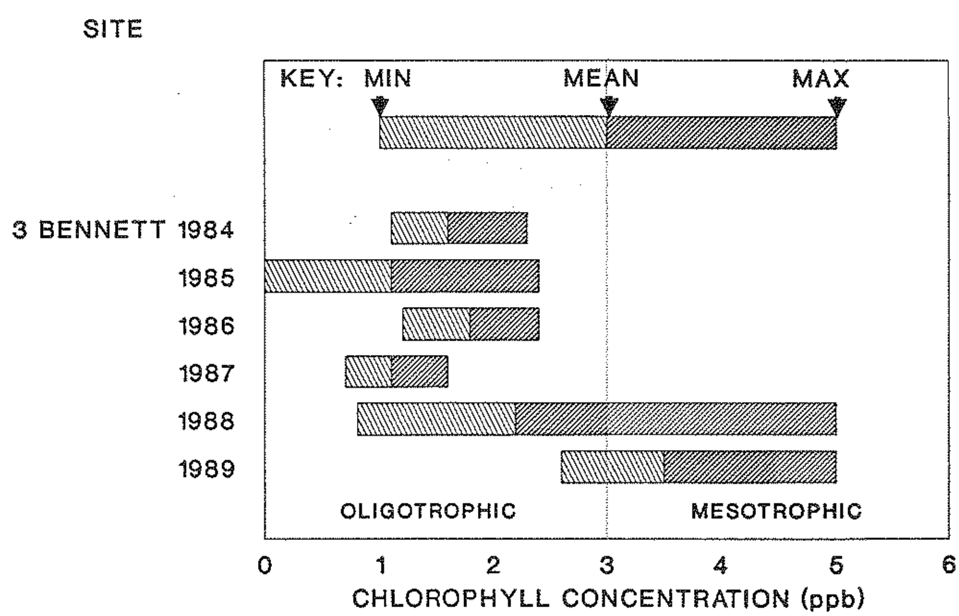
Figure 16. - Comparison of Site 3 Bennett (1989) Chlorophyll *a* Concentration with previous yearly data. The patterns of the bars display the minimum, mean and maximum values for each year sampled while the length of the bar represent the total range of values. The greater the concentration of chlorophyll *a* the "greener" the pond (more algae growth).

COMPARISON: 1984 TO 1989 DATA
BOW LAKE CHLOROPHYLL
CONCENTRATION



The higher number = more algae

COMPARISON: 1984 TO 1989 DATA
BOW LAKE CHLOROPHYLL
CONCENTRATION



The higher number = more algae

Bow Lake Data on file as of 04/17/1989

Lakes Lay Monitoring Program, U.N.H.

[Lay Monitor Data]

Bow Lake, NH
-- subset of trophic indicators, all sites, 1988

1988 SUMMARY

Average transparency:	5.1	(1988:	14	values;	4.5	-	6.3	range)
Average chlorophyll:	2.1	(1988:	14	values;	0.8	-	5.0	range)
Average phosphorus:	9.9	(1988:	7	values;	7.1	-	19.8	range)
Average trib phosp:	12.2	(1988:	11	values;	4.6	-	32.6	range)
Average alk (gray):	2.7	(1988:	14	values;	2.4	-	3.3	range)
Average alk (pink):	3.2	(1988:	14	values;	2.4	-	3.8	range)
Average color, 440:	36.8	(1988:	14	values;	12.9	-	122.8	range)

Site	Date	Trans-parency (m)	Chl a (ppb)	Total Phos (ppb)	Alk. (gray) ph 5.1	Alk. (pink) ph 4.6	Color Pt-Co units
1 Bottom	08/10/1988	---	---	19.8	---	---	---
1 Ledges	07/28/1988	6.3	1.4	---	2.6	3.0	23.2
1 Ledges	08/17/1988	5.3	1.8	---	2.4	2.8	18.9
1 Ledges	08/25/1988	4.7	1.8	---	2.7	3.1	18.0
1 Ledges	08/31/1988	5.5	1.9	9.5	2.8	3.2	23.2
1 Ledges	09/08/1988	4.5	1.5	---	2.6	3.2	24.9
1 Ledges	09/13/1988	4.5	2.7	8.6	3.0	3.5	30.9
1 Ledges	09/27/1988	5.0	2.2	---	3.3	3.8	122.8
2 Dam	08/31/1988	---	---	7.9	---	---	---
3 Bennett	07/28/1988	6.0	1.4	---	2.7	3.1	18.9
3 Bennett	08/17/1988	5.6	2.1	---	2.5	2.8	12.9
3 Bennett	08/25/1988	5.0	1.9	---	2.6	3.0	19.8
3 Bennett	08/31/1988	5.0	2.1	7.7	2.9	3.4	18.9
3 Bennett	09/08/1988	5.0	0.8	---	2.6	3.2	37.8
3 Bennett	09/13/1988	4.5	2.3	7.1	3.0	3.5	23.2
3 Bennett	09/27/1988	4.5	5.0	---	2.7	3.0	121.1
3 Bottom	08/10/1988	---	---	9.0	---	---	---
4 T. Park	08/31/1988	---	---	4.6	---	---	---
4 T. Park	09/13/1988	---	---	10.1	---	---	---
Peter Bk.	08/31/1988	---	---	21.2	---	---	---
Peter Bk.	09/13/1988	---	---	32.6	---	---	---
Foss Brk.	08/31/1988	---	---	7.9	---	---	---
Nrth Bdg	08/31/1988	---	---	9.0	---	---	---
Nrth Bdg.	09/13/1988	---	---	7.7	---	---	---

Site	Date	Trans-parency (m)	Chl a (ppb)	Total Phos (ppb)	Alk. (gray) ph 5.1	Alk. (pink) ph 4.6	Color Pt-Co units
Brn Past	08/31/1988	---	---	9.9	---	---	---
Brn Past	09/13/1988	---	---	8.2	---	---	---
Kook Isl	09/13/1988	---	---	14.8	---	---	---
Benn Isl	08/31/1988	---	---	7.7	---	---	---

<< End of 1988 listing, 28 records >>

Bow Lake Data on file as of 02/05/1990

Lakes Lay Monitoring Program, U.N.H.

[Lay Monitor Data]

Bow Lake, NH
-- subset of trophic indicators, all sites, 1989

1989 SUMMARY

Average transparency:	5.5	(1989:	12	values;	4.5	-	7.5	range)
Average chlorophyll:	3.5	(1989:	12	values;	2.5	-	5.0	range)
Average alk (gray):	3.5	(1989:	12	values;	3.0	-	3.8	range)
Average alk (pink):	4.2	(1989:	12	values;	4.0	-	4.7	range)
Average color, 440:	12.1	(1989:	12	values;	10.1	-	16.9	range)

Site	Date	Trans-parency (m)	Chl a (ppb)	Total Phos (ppb)	Alk. (gray) ph 5.1	Alk. (pink) ph 4.6	Color Pt-Co units
1 Ledges	06/20/1989	4.5	2.6	---	3.0	4.3	11.8
1 Ledges	07/08/1989	4.8	4.3	---	3.1	4.0	11.8
1 Ledges	07/18/1989	5.1	4.1	---	3.5	4.2	10.1
1 Ledges	08/01/1989	5.0	3.9	---	3.8	4.7	10.1
1 Ledges	08/15/1989	6.8	2.8	---	3.6	4.3	16.9
1 Ledges	09/09/1989	7.5	2.5	---	3.5	4.0	10.1
3 Bennett	06/20/1989	4.5	2.6	---	3.5	4.3	14.3
3 Bennett	07/09/1989	5.0	3.7	---	3.1	4.1	10.1
3 Bennett	07/18/1989	5.0	4.1	---	3.5	4.1	10.1
3 Bennett	08/01/1989	5.5	3.0	---	3.8	4.6	11.8
3 Bennett	08/15/1989	6.1	5.0	---	3.6	4.2	15.2
3 Bennett	09/09/1989	6.7	2.8	---	3.5	4.0	12.6
3 Bennett	09/13/1989	7.0	3.1	---	3.5	4.0	9.2
3 Bennett	09/25/1989	5.5	4.2	---	3.5	4.0	9.2

<< End of 1989 listing, 14 records >>

METHODS OF THE LAY MONITORS

Lay monitors receive their initial training either on-site or on campus from a member of the **FBG**. Workshops covering new techniques are usually offered on a yearly basis and updates may be held on-site during an **FBG** sampling trip.

1988 and 1989 data were collected on six parameters: thermal stratification, water clarity (secchi disk depth), total phosphorus (1988 only), chlorophyll a concentration, total alkalinity and dissolved color. Whenever possible, testing was done weekly between the hours of 9 am and 3 pm, the period of maximum sunlight penetration into the water. All samples and data were mailed or hand delivered to the **FBG** at **UNH** for analysis.

Thermal (temperature) profiles were obtained by collecting lakewater samples at several successive depths using a modified Meyer bottle (Lind, 1979). A weighted, stoppered, empty bottle was lowered to a specific depth. At that depth, the stopper was pulled, allowing the bottle to be filled with water. The bottle was quickly pulled back up to the surface where the temperature of the sample was taken with a Taylor pocket thermometer, and recorded in degrees C. This procedure was repeated at one meter intervals through the epilimnion (upper water column), at one-half meter intervals throughout the metalimnion (depths at which the temperature change is greater than 1 degree C per meter) and at one meter intervals through the hypolimnion (depths below the metalimnion). An alternative procedure uses an electronic thermocouple thermometer instead of the bottle and pocket thermometer to obtain the temperature profile.

Water clarity was measured by lowering a secchi disk (approximately 20 cm. or 8 inches) through the water off the shaded side of the boat, and noting the average of the depths at which it disappeared upon lowering and reappeared when being raised (the cord attached to the secchi disk is marked in one tenth of a meter for the first half meter and in one-half meters thereafter). Water clarity was determined while holding a view-scope just below the surface to eliminate effects of surface reflection and wave action. This was repeated two or three times, and an average to the nearest one-tenth of a meter was recorded.

Chlorophyll a concentration was used as an index of algal biomass that is useful in determining the trophic state of the lake. A weighted plastic tube (10 meters in length) was lowered through the epilimnion to the top of the metalimnion (the depths of the epilimnion and metalimnion are determined from the temperature profile). The end of the tube above water is folded to shut off the water flow into or out of the tube. The weighted end of the tube is pulled up out of the water with an attached cord, trapping an integrated sample of water representing the "upper lake" in the tube. This sample is poured into a blue plastic 2.5 liter bottle and stored in the shade until chlorophyll filtration could be done.

Water samples for chlorophyll a filtration were filtered through a 0.45 micron membrane filter under low vacuum. Damp filters, containing chlorophyll-bearing algae, were air-dried for at least 1 hour, in the dark, to prevent decomposition or bleaching of the chlorophyll on the filter. These filters were sent to UNH where members of the **FBG** analyzed them for chlorophyll a (see Methods of the Freshwater Biology Group).

Dissolved water color was determined by saving the filtrate from the chlorophyll filtration and storing it frozen in a 50 ml plastic bottle. The bottles were sent to UNH and the color was analyzed by the **FBG** team (see Methods of the Freshwater Biology Group).

METHODS OF THE FRESHWATER BIOLOGY GROUP

In 1989 the Freshwater Biology Group (FBG) research team took 1 trip to Bow Lake and conducted several tests which included measurements of sunlight penetration into the water, dissolved oxygen, alkalinity, free (unbound) carbon dioxide, pH, specific conductivity, chlorophyll a, dissolved color, total phosphorus, and a survey of the microscopic plants (phytoplankton) and animals (zooplankton).

Field and Laboratory Methods

At the deep water stations on the lake, a dissolved oxygen and temperature profile was taken using a Yellow Springs Instruments Model 54A Oxygen/Temperature meter with a submersible probe. Readings were taken at one-meter intervals throughout the epilimnion and hypolimnion, and at one-half meter intervals through the metalimnion.

Water transparency was measured by lowering a secchi disk (approximately 20 cm diameter) through the water off the shaded side of the boat, and noting the average of the depths at which the disk disappeared upon lowering and reappeared when raised. A view scope was held just at the water surface to eliminate effects of surface reflection and wave action. This was repeated two or three times and the average value to the nearest one-tenth meter was recorded.

Sunlight and skylight penetration into the water was measured with a Whitney submersible photometer model LMA-8A, off the sunny side of the boat. The coefficient of light extinction was calculated from the relative light intensities measured.

Samples of lake water to be analyzed for dissolved oxygen, alkalinity, free (unbound) carbon dioxide, pH, and specific conductivity were collected with a 3-liter Van Dorn bottle at depths that represented the surface, mid-epilimnion, metalimnion, and hypolimnion of the two deep water sites. Shore lake water samples were collected 0.5 to 1 meter below the lake surface. Alkalinity, free carbon dioxide, and pH samples were stored on ice in 250 milliliter polyethylene bottles and were analyzed in the field generally within

1 to 2 hours of sampling. Specific conductivity was measured in the FBG lab at room temperature.

In addition to the oxygen profile taken, the dissolved oxygen (DO) concentration of specific lake water samples (epilimnetic and hypolimnetic) were determined chemically with the azide modification of the Winkler method (EPA 1979). The precision of the method provides a standard for the electronic probe. Water is collected in 350 ml biological oxygen demand (BOD) bottles and fixed with two reagents, manganese sulfate and alkaline-iodide-azide. A loose precipitate (floc) of manganic hydroxide is formed that is equivalent to all dissolved oxygen originally present in the sample. Concentrated sulphuric acid is added to the bottle which causes a stoichiometric release of dissolved iodine equal to the original amount of dissolved oxygen present. A known quantity of sample is then titrated to an end point using .0250N phenylarsine oxide titrant (similar to, but more stable than, sodium thiosulphate which may also be used) and a starch indicator solution. The end point is reached when the purple colored iodine-starch complex is reduced and the solution becomes colorless . The amount of titrant added was recorded to the nearest 0.1 ml and concentrations are reported to the nearest 0.2 milligrams dissolved oxygen per liter.

To determine the alkalinity, lake water samples were titrated with 0.002 N sulphuric acid in the presence of the indicator methyl red/bromocresol green to a pH of 5.1 (grey endpoint) and 4.6 (pink endpoint). The amount of titrant used (dilute sulphuric acid) was recorded to the nearest 0.1 ml, equivalent to milligrams of calcium carbonate per liter. Values reported can be converted to microequivalents of calcium carbonate using a multiplication factor of 20.

"Free" carbon dioxide concentration was determined by titrating the fresh lake water samples with 0.0027 N sodium hydroxide to a final endpoint pH of 8.3, in the presence of the indicator dye phenolphthalein.

Lake water pH was measured with a digital pH meter (Beckman model phi 44) equipped with a low ionic strength combination probe and an automatic temperature compensating probe. The meter was calibrated with pH 4 and pH 7 buffer solutions and then the probe was allowed to equilibrate in lake water for at least thirty minutes prior to sample analysis.

Specific conductivity was measured with a Barnstead Conductivity Bridge Model PM-70CB , with a model B-10 probe (cell constant = 1.0). Corrections were made for sample temperatures with a standard curve of potassium chloride solution conductivity versus temperature. Results are reported as micro-Siemens (uS, where uS equals umho cm^{-2}) standardized to 18^{o} C.

Chlorophyll a concentration was used as an index of algal biomass that is useful in determining the trophic state of the lake. A weighted plastic tube was lowered through the epilimnion to just above the thermocline (as measured with the YSI oxygen temperature meter). The top end of the tube was folded to shut off water flow into or out of the tube and the bottom end was pulled up quickly to collect the integrated sample. The sample was poured into a dark blue plastic 2.5 liter bottle and promptly placed in a cooler. Point samples of chlorophyll were collected at the metalimnion with the Van Dorn sampler. Chlorophyll samples were filtered through a 0.45 micron membrane filter and air-dried in the dark until analysis. The chlorophyll a content was analyzed by extracting the chlorophyll with a 90% acetone solution saturated with magnesium carbonate. The samples were then centrifuged and their light absorbance read at two standard wavelengths (663 and 750 nanometers) with a Milton Roy model 1001+ spectrophotometer equipped with 50mm cuvettes. An absorptivity value of 84 gm $liter^{-1}$ cm^{-1} (Vollenweider 1969) was used for calculating the concentrations.

Dissolved color of the filtrate from chlorophyll filtrations was determined by reading the absorbance of the samples at two different wavelengths (440 and 493 nanometers) in a 50mm light path. The two readings were converted to the more widely used platinum cobalt color values with our standard curves of the absorbance of chloroplatinate.

Phosphorus samples were preserved with 1.0 milliliter of concentrated sulphuric acid and refrigerated or frozen until analysis. To determine the total phosphorus content, ammonium persulfate and 11 N sulphuric acid was added to digest the total phosphorus, and the samples were autoclaved for thirty minutes at 150 to 170 degrees C. Reagents included potassium antimony tartrate, ammonium molybdate, and a solution of ascorbic acid mixed fresh before each sample run (APHA 1985, EPA 1979). Absorbance of the blue phosphorus complex was measured with the spectrophotometer at 650 and 880 nanometers. A standard curve of the absorbance of a potassium phosphate (monobasic) solution was used to convert the readings to total phosphorus concentrations. Each sample was analyzed twice and an average of the two values was recorded as the phosphorus content in parts per billion (ppb).

At selected stations and depths 60 ml of water from the Van Dorn was collected for phytoplankton analysis. On some occasions an integrated sample was collected with a vertical tube sampler lowered through the epilimnion. Phytoplankton samples were preserved with iodine (Lugol's solution) immediately after collection. Algae were later identified and counted with an inverted microscope after settling for 24 hours in 5 or 10 ml counting chambers. At least 200 individual algal "units" were counted with a modified scan technique (Baker, 1973). Phytoplankton are reported to species level whenever possible.

At the deep water stations zooplankton samples were collected with a plankton net (30 centimeter diameter, 80 micron porosity) towed vertically through the oxygenated portion of the water (>0.5 ppm oxygen). Samples were immediately preserved in a 4% formalin-sucrose solution (Haney and Hall, 1973). Organisms were identified to species whenever possible. Sub-sampling, whenever necessary, was done with a 1 ml Hensen-Stemple pipette. Repeated sub-samples were analyzed until at least 100 organisms were counted.

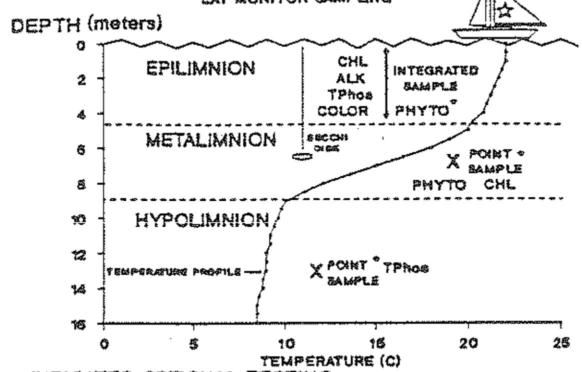
Data Analysis

All field and laboratory data was filed and stored on the **FBG** computerized data management system that utilizes a mainframe DEC VAX-8650 computer and an IBM compatible micro-computer (Zenith Data Systems 158). With full use of relational data bases, such as S1032 and Dbase III, data can be retrieved easily by date, station, or by parameter for within-lake comparison, or between-lake comparisons with other lake data bases (Lakes Lay Monitoring Program, New Hampshire Water Supply and Pollution Control, N.H. Fish and Game, EPA Surface Water Survey and others). Spreadsheet, statistics and graphics packages on both the mainframe and micro-computer enable data analysis and presentation.

Although it is not within the scope of this report, the **FBG** also stores historical information for Bow Lake to help estimate trends in lake water quality after adequate long-term data collection.

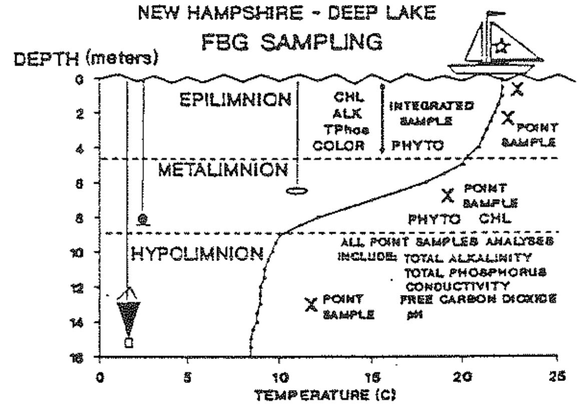
Trophic boundaries of Forsberg and Ryding (1980) of transparency, chlorophyll a, and total phosphorus are used as criteria in discussions of the trophic state of Bow Lake. Phytoplankton are reported both as species and classes. Crustacean zooplankton were identified to genus or species and classified into one of four categories depending on their size (large or small) and their feeding preferences (herbivore or predator) with a modified version of criteria from Sprules (1980). The differences in abundance between the different groups allow for a more complete description of the zooplankton community and the trophic classification of lakes.

TYPICAL TEMPERATURE CONDITIONS : SUMMER
NEW HAMPSHIRE - DEEP LAKE
LAY MONITOR SAMPLING

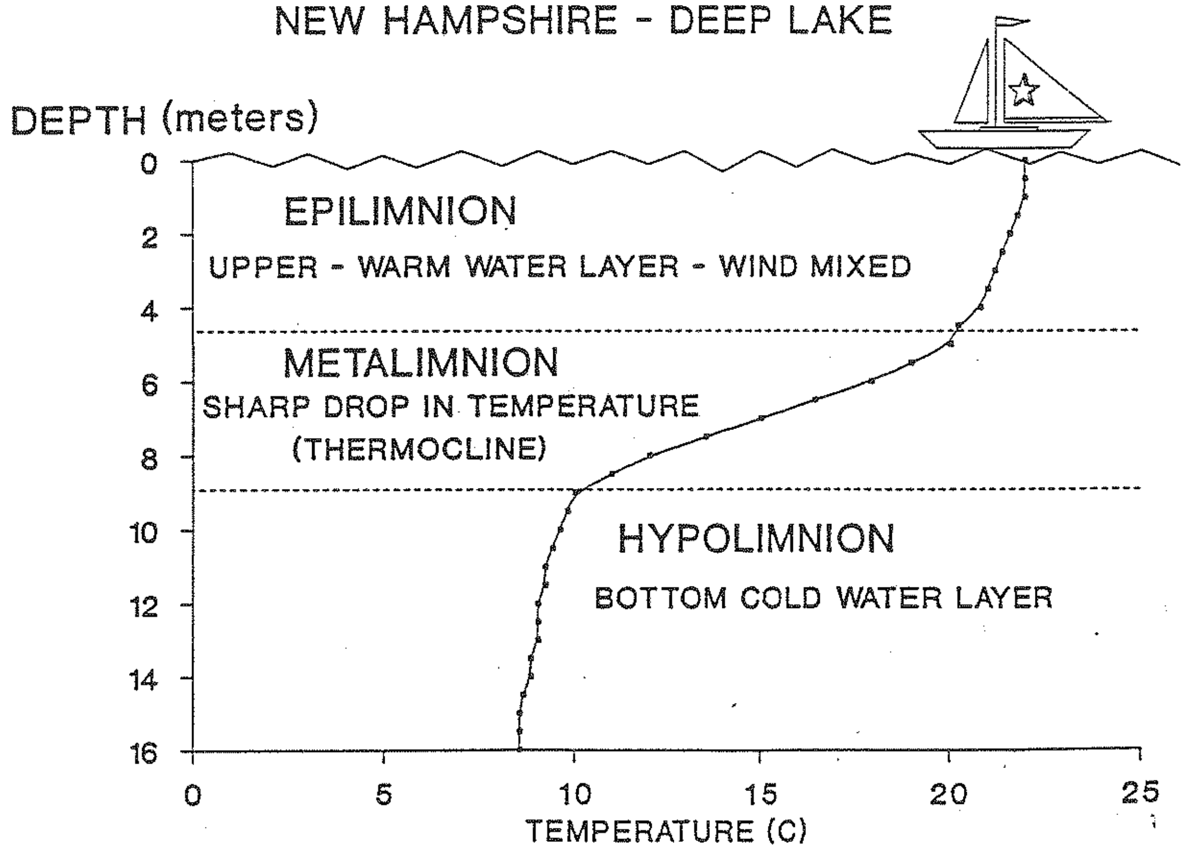


* - INDICATES OPTIONAL TESTING

TYPICAL TEMPERATURE CONDITIONS : SUMMER
NEW HAMPSHIRE - DEEP LAKE
FBG SAMPLING



TYPICAL TEMPERATURE CONDITIONS : SUMMER
NEW HAMPSHIRE - DEEP LAKE



APPENDIX C

GLOSSARY OF LIMNOLOGICAL TERMS

Aerobe- Organisms requiring oxygen for life. All animals, most algae and some bacteria require oxygen for respiration.

Algae- See phytoplankton.

Alkalinity- Total concentration of bicarbonate and hydroxide ions (in most lakes).

Anaerobe- Organisms not requiring oxygen for life. Some algae and many bacteria are able to respire or ferment without using oxygen.

Anoxic- A system lacking oxygen, therefore incapable of supporting the most common kind of biological respiration, or of supporting oxygen-demanding chemical reactions. The deeper waters of a lake may become anoxic if there are many organisms depleting oxygen via respiration, and there is little or no replenishment of oxygen from photosynthesis or from the atmosphere.

Benthic- Referring to the bottom sediments.

Bacterioplankton- Bacteria adapted to the "open water" or "planktonic" zone of lakes, adapted for many specialized habitats and include groups that can use the sun's energy (phytoplankton), some that can use the energy locked in sulfur or iron, and others that gain energy by decomposing dead material.

Bicarbonate- The most important ion (chemical) involved in the buffering system of New Hampshire lakes.

Buffering- The capacity of lakewater to absorb acid with a minimal change in the pH. In New Hampshire the chemical responsible for buffering is the bicarbonate ion. (See pH.)

Chloride- One of the components of salts dissolved in lakewater. Generally the most abundant ion in New Hampshire lakewater, it may be used as an indicator of raw sewage or of road salt.

Chlorophyll a- The main green pigment in plants. The concentration of chlorophyll a in lakewater is often used as an indicator of algal abundance.

Circulation- The period during spring and fall when the combination of low water temperature and wind cause the water column to mix freely over its entire depth.

Density- The weight per volume of a substance. The more dense an object, the heavier it feels. Low-density liquids will float on higher-density liquids.

Dimictic- The thermal pattern of lakes where the lake circulates, or mixes, twice a year. Other patterns such as polymictic (many periods of circulation per year) are uncommon in New Hampshire. (See also meromictic and holomictic).

Dystrophy- The lake trophic state in which the lakewater is highly stained with humic acids (reddish brown or yellow stain) and has low productivity. Chlorophyll a concentration may be low or high.

Epilimnion- The uppermost layer of water during periods of thermal stratification. (See lake diagram).

Eutrophy- The lake trophic state in which algal production is high. Associated with eutrophy is low Secchi disk depth, high chlorophyll a, and low total phosphorus. From an esthetic viewpoint these lakes are "bad" because water clarity is low, aquatic plants are often found in abundance, and cold-water fish such as trout and salmon are usually not present. A good aspect of eutrophic lakes is their high productivity in terms of warm-water fish such as bass, pickerel, and perch.

Free CO2- Carbon dioxide that is not combined chemically with lake water or any other substances. It is produced by respiration, and is used by plants and bacteria for photosynthesis.

Holomixis- The condition where the entire lake is free to circulate during periods of overturn. (See meromixis.)

Humic Acids-Dissolved organic compounds released from decomposition of plant leaves and stems. Humic acids are red, brown, or yellow in color and are present in nearly all lakes in New Hampshire. Humic acids are consumed only by fungi, and thus are relatively resistant to biological decomposition.

Hydrogen Ion- The "acid" ion, present in small amounts even in distilled water, but contributed to rain-water by atmospheric processes, to ground-water by soils, and to lakewater by biological organisms and sediments. The active component of "acid rain". See also "pH" the symbolic value inversely and exponentially related to the hydrogen ion.

Hypolimnion-The deepest layer of lakewater during periods of thermal stratification.

Lake- Any "inland" body of relatively "standing" water. Includes many synonyms such as ponds, tarns, loches, billabongs, bogs, marshes, etc.

Lake Morphology- The shape and size of a lake and its basin.

Littoral- The area of a lake shallow enough for submerged aquatic plants to grow.

Meromixis- The condition where the entire lake fails to circulate to its deepest points; caused by a high concentration of salt in the deeper waters, and by peculiar landscapes (small deep lakes surrounded by hills and/or forests. (Contrast holomixis.)

Mesotrophy- The lake trophic state intermediate between oligotrophy and eutrophy. Algal production is moderate, and chlorophyll a, Secchi disk depth, and total phosphorus are also moderate. These lakes are aesthetically "fair" but not as good as oligotrophic lakes.

Metalimnion-The "middle" layer of the lake during periods of summer thermal stratification. Usually defined as the region where the water temperature changes at least one degree per meter depth. Also called the thermocline.

Mixis- Periods of lakewater mixing or circulation.

Mixotrophy- The lake condition where the water is highly stained with humic acids, but algal production and chlorophyll a values are also high.

Oligotrophy- The lake trophic state where algal production is low, Secchi disk depth is deep, and chlorophyll a and total phosphorus are low. Aesthetically these lakes are the "best" because they are clear and have a minimum of algae and aquatic plants. Deep oligotrophic lakes can usually support cold-water fish such as lake trout and land-locked salmon.

Overturn- See circulation or mixis

pH- A measure of the hydrogen ion concentration of a liquid. For every decrease of 1 pH unit, the hydrogen ion concentration increases 10 times. Symbolically, the pH value is the "negative logarithm" of the hydrogen ion concentration. For example, a pH of 5 represents a hydrogen ion concentration of 10^{-5} molar. [Please thank the chemists for this lovely symbolism -- and ask them to explain it in lay terms!] In any event, the higher the pH value, the lower the hydrogen ion concentration. The range is 0 to 14, with 7 being neutral 1 denoting high acid condition and 14 denoting very basic condition.

Photosynthesis- The process by which plants convert the inorganic substances carbon dioxide and water into organic glucose (sugar) and oxygen using sunlight as the energy source. Glucose is an energy source for growth, reproduction, and maintenance of almost all life forms.

Phytoplankton- Microscopic algae which are suspended in the "open water" zone of lakes and ponds. A major source of food for zooplankton. Common examples include: diatoms, euglenoids, dinoflagellates, and many others. Usually included are the blue-green bacteria.

Parts per million- Also known as "ppm". This is a method of expressing the amount of one substance (solute) dissolved in another (solvent). For example, a solution with 10 ppm of oxygen has 10 pounds of oxygen for every 999,990 pounds (500 tons) of water. Domestic sewage usually contains from 2 to 10 ppm phosphorus.

Parts per billion- Also known as "ppb". This is only 1/1000 of ppm, therefore much less concentrated. As little as 1 ppb of phosphorus will sustain growth of algae. As little as 10 ppb phosphorus will cause algal blooms! Think of the ratio as 1 milligram (1/28000 of an ounce) of phosphorus in 25 barrels of water (55 gallon drums)! Or, 1 gallon of septic waste diluted into 10,000 gallons of lakewater. It adds up fast!

Plankton- Community of microorganisms that live suspended in the water column, not attached to the bottom sediments or aquatic plants. See also "bacterioplankton" (bacteria), "phytoplankton" (algae) and "zooplankton" (microcrustaceans and rotifers).

Saturated- When a solute (such as water) has dissolved all of a substance that it can. For example, if you add table salt to water, a point is reached where any additional salt fails to dissolve. The water is then said to be saturated with table salt. In lakewater, gaseous oxygen can dissolve, but eventually the water becomes saturated with oxygen if exposed sufficiently long to the atmosphere or another source of oxygen.

Specific Conductivity- A measure of the amount of salt present in lakewater. As the salt concentration increases, so does the specific conductivity (electrical conductivity).

Stratum- A layer or "blanket". Can be used to refer to one of the major layers of lakewater such as the epilimnion, or to any layers of organisms or chemicals that may be present in a lake.

Thermal Stratification- The process by which layers are built up in the lake due to heating by the sun and partial mixing by wind.

Thermocline- Region of temperature change. (See metalimnion.)

Total Phosphorus- A measure of the concentration of phosphorus in lakewater. Includes both free forms (dissolved), and chemically combined form (as in living tissue, or in dead but suspended organisms).

Trophic Status- A classification system placing lakes into similar groups according to their amount of algal production. (See Oligotrophy, Mesotrophy, Eutrophy, Mixotrophy, and Dystrophy for definitions of the major categories)

Z- A symbol used by limnologists as an abbreviation for depth.

Zooplankton- Microscopic animals in the planktonic community. Some are called "water fleas", but most are known by their scientific names. Scientific names include: Daphnia, Cyclops, Bosmina, and Kellicottia.